DETRITAL ZIRCON TRACE ELEMENT CHARACTERIZATION OF MIDDLE TO LATE ORDOVICIAN QUARTZ ARENITES ALONG THE TRANSCONTINENTAL ARCH

A Thesis

by

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ABSTRACT

During the Middle to Late Ordovician, Laurentia was situated over the equator and the Transcontinental Arch, and its exposed basement rock and sedimentary cover straddled the equator. This resulted in unique siliciclastic deposition of a diachronous group of quartz arenites during an otherwise long interval of almost entirely carbonate deposition. In recent years, a rapidly expanding database, especially in laser ablation – inductively coupled plasma mass spectrometry (LA-ICPMS) geochronology, has led to significant advances in understanding the provenance of these quartz arenites on both sides of the Transcontinental Arch, the passive margin of western Laurentia and US Midcontinent. Detrital zircon from quartz arenite samples were previously dated using U-Pb methods to make interpretive correlations between detrital zircons and their source terranes. However, age data alone do not always uniquely discriminate between potential source regions. To aid in further discrimination, an LA-ICPMS analytical method was developed to obtain trace-elemental composition data from detrital zircons that were previously analyzed for U-Pb ages. When coupled with U-Pb geochronologic data, this additional geochemical data can serve as an improved reference for discrimination between source terranes. Trace element diagrams (e.g. REE plots) are used as discrimination diagrams to differentiate between potential source regions that are of similar age. Results of this study indicate that there are no significant resolvable differences in zircon trace element compositions that can be correlated with differences in U-Pb age spectra from the quartz arenite samples.

DEDICATION

I would like to dedicate this thesis to my parents, John and Susan, who helped more than they will ever truly know. I am so grateful to you both for making me the man I am today and always supporting me on my past and future endeavors. To my sister, Hannah, thank you for always being there for me when times were tough. You're the best sister any brother could ever ask for. To the two best friends a guy could ask for, Frank & Phil, I could not have got through this without you guys. I would like to also dedicate this thesis to my Aunt and Uncle, Jane and Bill, and to my grandparents, Arnold and Alice. For the amount of time you all spent with me growing up, thank you for everything you have done for me and taught me through the years. Finally, to Dr. Brent Miller, thank you for all of your guidance over the past 5 years as an undergraduate and graduate student, you have been much more than just an advisor to me. All of you have truly gone above and beyond for me, and for that I am truly grateful.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Page

1. INTRODUCTION

Over the last thirty years, numerous studies have used U-Pb dating of detrital zircons as a tracer of sediment provenance in order to provide insight into paleogeography, sedimentary dispersal systems, sedimentological effects from changing sea level, and tectonic reconstructions among other applications (e.g. Thomas, 2011; Gehrels, 2012). This is possible because zircon is a common accessory mineral in igneous and metamorphic rocks, being both physically and chemically resistant in a wide range of geological environments (Fedo et al., 2003). Zircon persists through erosion, transportation, deposition, diagenesis, metamorphism and even some melting conditions. In addition to their application for U-Pb dating, zircons are robust repository for trace elements, which can provide insight into the petrogenesis of the parent rock. Thus, combining detrital zircon U-Pb dating with trace element petrogenesis has recently begun to emerge as a more powerful provenance analysis tool (e.g. Belousova et al., 2002; Nardi et al., 2013)

The large increase in detrital zircon provenance studies is due in large part to the introduction and continuing improvements in Laser Ablation-Inductively Coupled Plasma-Mass Spectrometry (LA-ICPMS) techniques (Jackson et al., 2004), which make feasible the large numbers of zircon U-Pb analyses required for statistical validity of sample detrital zircon age populations (e.g. Vermeesch, 2004). However, age data are not always unique discriminators of a potential source region (Gehrels, 2012) because one zircon age population could be derived from more than one potential source region with rocks of varying origin and petrogenesis, and thus varying trace element characteristics. Additional geochemical data can help to better discriminate between source regions of similar age (Andersen, 2005; Thomas, 2011). For example, hafnium isotope ratios in zircon commonly are the focus of complementary geochemical data because they can potentially differentiate zircons derived from isotopically juvenile source terranes from those that are isotopically more evolved (Owen, 1987; Sevastjanova et al., 2011; Fisher et al., 2014). Recent methodological improvements have enabled other complementary trace-elemental compositional data to be simultaneously collected with age data during analyses (Yuan et al., 2008), and this has opened up a wide array of new geochemical provenance analysis tools such as rare earth element (REE) signatures (Belousova et al., 2002), Ti thermometry (Watson et al., 2006; Fu et al., 2008), and other trace elements with petrogenetic significance (e.g. Nardi et al., 2013).

This study applies trace-element discrimination methods in zircon to the problem of zircon provenance in Middle to Late Ordovician quartz arenites along the Transcontinental Arch (Fig. 1). These quartz arenites were deposited along the Lower Paleozoic passive margin of western Laurentia and U.S. Midcontinent (referred to as western margin and midcontinent herein, respectively). Previous detrital zircon geochronology studies (Gehrels, 1995; Gehrels, 2000; Baar, 2008; Wulf, 2011; Hutto, 2012; Pickell, 2012; Workman, 2012; Ibrahim, pers. comm., 2015; Lira, pers. comm. 2015) on this diachronous group of Middle-Late Ordovician quartz arenites of North America have helped to constrain sediment provenance. However, age data alone may not provide a unique provenance “fingerprint”, as similar detrital zircon age distributions exist between the western margin and midcontinent samples. This “provenance problem” stems from the presence of multiple similar-age Archean, Paleoproterozoic, and 1.2 – 0.8 Ga provinces that could be the sediment source regions, however these source regions are underlain by very different rock types. Outlined here is a methodological approach of LA-ICPMS trace element analysis of zircons applied to the problem of attempting to discriminate between detrital zircons of the western margin and midcontinent in Middle-Late Ordovician quartz arenites.

1.1 Geologic Background

During the Middle-Late Ordovician, the Transcontinental Arch of Laurentia was oriented along the paleoequator (Mac Niocaill et al., 1997; Scotese, 2004), and acted as both a local sediment source and topographic barrier between the western margin and midcontinent (Fig. 1). Both the western margin and midcontinent of Laurentia were dominated by thick carbonate successions (Webb, 1958; Ketner, 1968). On both sides of the arch, distinctive quartz arenite units, typically 50-150 m thick, were deposited during an otherwise long interval of almost entirely carbonate deposition (Fig. 2). Early work suggested deposition of these distinctive units occurred during a prolonged Middle Ordovician sea level lowstand (Webb, 1958). However, recent biostratigraphic data (Sweet, 2000) has constrained some of these sandstone units to be as young as Cincinnatian in age (451-443.5 Ma, Gradstein et al., 2012), suggesting deposition during extensive continental flooding following the Middle Ordovician lowstand (Algeo and Seslavinsky, 1995). A greenhouse global climate existed during the Middle Ordovician, likely increasing the weathering of exposed regions of Laurentia. During the Middle-Late Ordovician, sea-level fluctuations influenced the geographic extent of exposed regions of Laurentia, which in turn affected the deposition and sediment provenance of Middle-Late Ordovician quartz arenites (Gehrels and Dickinson, 1995; Gleason et al., 2002; Pope et al., 2011).

1.2 Previous Work

Early provenance studies of Middle-Late Ordovician siliciclastic units focused on rocks deposited along the western margin of Laurentia using Thermal Ionization Mass Spectrometry (TIMS) of 158 zircon grains from four samples (Gehrels et al., 1995; Gehrels, 2000). Their results, limited to age data alone, suggested the Peace River Arch region was the dominant source terrane for much of the sediment along the western margin. The interpreted dispersal mechanism of longshore drift and the volume of sediment needed to produce the Middle-Late Ordovician quartz arenites has been challenged by alternative sediment dispersal models (Pope et al., 2011). Recent work takes advantage of the new improvements in Laser-Ablation-Inductively-Coupled-Mass-Spectrometry (LA-ICPMS) to constrain ages, and to build a sequence stratigraphic framework. Detrital zircon age spectra for these siliciclastic units have distinct age populations, dependent upon sample location. Distinct age populations along the western margin (Fig. 3) are: 2.0 – 1.8 Ga, 2.8 – 2.5 Ga, 1.2 – 0.8 Ga, 1.8 – 1.6 Ga, and 2.2 – 2.05 Ga (Gehrels, pers. comm. 2008; Wulf, 2011; Hutto, 2012; Workman, 2012; Lira, pers. comm. 2015). Age populations for the midcontinent are: 1.8 – 1.6 Ga, 2.0 – 1.8 Ga, 2.8 – 2.5 Ga, 1.55 – 1.3 Ga, and 1.2 – 0.8 Ga (Pickell, 2012; Ibrahim, pers. comm. 2015).

Regardless of location, all samples have distinct age populations of 2.0 – 1.8 Ga, 2.8 – 2.5 Ga, and 1.2 – 0.8 Ga. Provenance shifts are recorded from lower to upper sections of the Ordovician units, interpreted from the U-Pb age spectra (Fig. 4). However, it is not clear whether there is any shift within any of the dominant age populations when these pronounced changes in provenance occur. Recent work by Gehrels and Pecha (2014) coupled Hf isotopes with age data, analyzing coeval Ordovician strata along the western margin of Laurentia. Their results suggest four main zircon source regions, in which Archean zircons were sourced from the northwest Canadian Shield with subsequent southward transport.

1.3 Laurentian Geochemical Signatures

As the aim of this study was to differentiate similar age source terranes using geochemical signatures, a review of similar-age source terranes is presented for Archean (>2.5 Ga), Paleoproterozoic (2.4 – 1.8 Ga), and Meso- to Neoproterozoic (1.2 – 0.8 Ga) bedrock regions of North America. Using published whole rock geochemical data from these source regions, geochemical trends such as light rare-earth element (LREE) and heavy rare-earth element (HREE) enrichments or depletions, large cerium or europium anomalies, and other elemental trends that are recorded in the whole rock composition can be used as patterns that differentiate between source terranes (Belousova et al., 2002). These geochemical signatures in the whole rock composition may also carry over into the compositions of zircon. Using experimentally determined partition coefficients (K_d) (e.g. Nardi et al., 2013), calculated zircon/chondrite REE patterns can be estimated for zircons from rocks of different composition and tectonic setting. These and other trace-element characteristics should impart into zircons some semblance of their distinctive trace element characteristics if the zircon compositions are governed by composition-dependent melt/crystal element partitioning. As the scope of this project is at a regional scale, geochemical signatures were compiled and aimed to represent the dominant lithologies of each province.

The variability of geochemical trends within source regions is expected to discriminate similar-age sources if REE concentrations in zircons reflect, through their partition coefficients (K_d), the concentrations of REE in the melt, which varies in systematic ways in rocks of different compositions and origins.

1.3.1 Archean Provinces

Archean detrital zircons in Ordovician quartz arenite samples are consistently present within the detrital zircon populations (Pope et al., 2011). Dominated by igneous and metamorphic rocks, the Wyoming, Superior, Hearne, Rae, Slave and Sask Craton provinces are the large Archean crustal provinces which amalgamated to form an extensive portion, approximately 8 million km^2, of the Laurentian continental core (Whitmeyer and Karlstrom, 2007). Whole-rock REE patterns of rocks from these provinces form groups with distinct characteristics indicative of rock type and tectonic setting.

1.3.1.1 Wyoming Province

The Wyoming province is characterized by three subprovinces: the Montana metasedimentary province (MMP), the Beartooth-Bighorn magmatic zone (BBMZ), and the Southern accreted terranes (SAT) (Mueller and Frost, 2006). The MMP is composed predominantly of (3.5-3.3 Ga) Archean quartzofeldspathic gneisses (Mueller et al., 2004b). The BBMZ is dominated by (3.0-2.8 Ga) trondhjemite-tonalite-granodiorite (TTG) associated metaplutonic rocks. The SAT is dominanted by Late Archean calc-alkalic magmatism occurring in three distinct pulses at 2.71-2.67, 2.65-2.62, and 2.55-2.50 Ga (Chamberlain et al., 2003). Interpreted as a long-lived active margin, the formation of the SAT produced a majority of the magmatism from 2.71-2.67 and 2.65-2.62 Ga (Frost et al., 1998), as well as amphibolites/granulites within the subprovinces to the north. Both the MMP and BBMZ have evidence of older Archean rocks (>3.0 Ga) from detrital zircons with inherent igneous cores of 4.0-3.3 Ga with surrounding metamorphic-aged rims (Mueller et al., 1992; Frost and Fanning, 2006).

These three subprovinces have distinct rock suites, which in turn have distinct whole rock REE patterns definitive from one another which are used to characterize the geochemical signatures of the Wyoming province. The Wyoming province has four main geochemical signatures (Fig. 5): 1) the TTG associated metaplutonic rocks of the BBMZ which exhibit a REE pattern typical of respective plutonic protoliths, a LREE enrichment, intense negative europium (Eu) anomaly, and a flat HREE pattern. 2) The quartzofeldspathic gneisses of the MMP which exhibit a LREE enrichment, a subtle negative Eu anomaly, and a HREE depletion. 3) The calc-alkaline magmatic rocks of the SAT exhibit a LREE enrichment and a HREE depletion. 4) The basalts, gabbros, and amphibolites which are interspersed within the subprovinces exhibit a REE pattern that is relatively flat with a terbium (Tb) anomaly.

1.3.1.2 Superior Province

The Superior province, the largest of all the Archean provinces, is characterized by many subprovinces which can be summarized by northern and southern regions of high-grade gneiss subprovinces and a central region of granite-greenstone belts dominated by plutonic, volcano-plutonic, and metasedimentary rocks (Card, 1990). The granite-greenstone belts, which comprises a majority of the Superior province, have zircon U-Pb ages of ca. 3.0-2.6 Ga. and a majority of dates at ca. 2.7 Ga.

Geochemical data compiled from granitoids of the granite-greenstone belts have two main signatures (Fig. 6), both with a LREE enrichment and a slight HREE depletion but with either a moderate positve Eu or no Eu anomaly. The large abundance of greenstone belts within the Superior province show a large degree of heterogeneity amongst rock types and, for the scope of this project, we consider these greenstone belts to represent metamorphosed volcanic belts in which potential zircons derived from these bodies retain their protolith geochemistry. The Archean basement gneisses are dominantly felsic with calc-alkaline affinity (Sims et al., 1993). REE patterns for gneiss assemblages exhibit a LREE enrichment, large -Eu anomaly, and a slight HREE depletion.

1.3.1.3 Sask Craton

The Sask Craton is an Archean microcontinent preserved in and surrounded by the Trans-Hudson orogeny (Bickford et al., 2005). Geochronologic data for the craton consists a majority of U-Pb zircon ages of 2.52 – 2.43 Ga from granitoid plutons and some ages as old as 3.1 Ga (Chiarenzelli et al., 1998; Rayner et al., 2005), limited by the small amount of surface exposure which hinders the full geochronological and geochemical understanding of the Sask Craton. However, the Sask Craton does separate itself from other Archean provinces with zircon ages as young as ca. 2.43 Ga. Granitoid basement rocks range from alkaline-granitic to tonalitic in composition. As no whole-rock trace element geochemistry occurs on the craton, we cannot present any geochemical characteristics on the region.

1.3.1.4 Hearne & Rae Provinces

The Hearne and Rae Archean provinces are combined here based on similarities in ages and rock type. Both provinces are dominated by 3.0 – 2.8 Ga grantic to mafic gneisses (Bickford et al., 1994), granitoid rocks (Bethune and Scammell, 2003; Hanmer et al., 2004) and volcanic rocks (Sandeman et al., 2004). Volcanic and plutonic rocks both range from 3.0 – 2.6 Ga. REE patterns (Fig. 7) of granitoid rocks have a moderate LREE enrichment, large -Eu anomaly, and a slight HREE depletion. Volcanic rocks have patterns, both with a slight enrichment of LREE and slight depletion in HREE, distinguishable by a large Sm and Nd enrichment. Basalts and gabbros within the province exhibit a similar relatively flat REE pattern.

1.3.1.5 Slave Province

The Slave province, the northwestern-most Archean province, is comprised of granitoid, metamorphic, and granite-greenstone belt regions. The Slave province has a high proportion of metasedimentary rocks, uniform granite-greenstone belts, and a lack of komatiites which distinguishes it from other Archean provinces (Helmstaed and Pehrsson, 2012). Granitic plutonism dominates a majority of rocks exposed within the

Slave craton, which include tonalities to granites. REE patterns of granitic plutons within the Slave craton (Fig. 8) have two different patterns. Granites have typical LREE enrichment, a large -Eu anomaly, and slight HREE depletion with near-flat slope. Tonalites exhibit a LREE enrichment and HREE depletion, with an unusual positive holmium (Ho) and negative erbium (Er) anomalies. Basaltic and andesitic volcanics from the greenstone belts exhibit rather flat REE patterns with a slight LREE enrichment, as do gabbroic rocks from the region.

1.3.2 Paleoproterozoic Provinces

The assembly of the Laurentian shield resulting from the collision of Archean plates and fragments, as well as the earliest Paleoproterozoic juvenile crust (2.4 – 2.0 Ga) occurred during the Paleoproterozoic (2.0 – 1.8 Ga), represented by the Trans-Hudson orogeny (THO) (Ansdell, 2005). The 2.4 – 2.0 Ga juvenile terranes are primarily limited to tectonic sections of the Wopmay and Taltson orogens in northwest Canada (Ross et al., 1991). Coeval with the THO are juvenile arcs and terranes which accreted along the outer-margins and between provinces of the Archean core and northwest Canada terranes (Hoffman, 1988). These juvenile imbrications all appear to be components of the Trans-Hudson orogenic system (Whitmeyer and Karlstrom, 2007).

1.3.2.1 Trans-Hudson Orogeny

The Trans-Hudson orogeny, located in northern Sasketchewan and Manitoba, represents the amalgamation of the Superior, Hearne, and Wyoming province at approximately 1.9 – 1.8 Ga (Whitmeyer and Karlstrom, 2007). The Trans-Hudson orogeny is dominated by orogenic, felsic-intermediate plutonic rocks, volcanic rocks and surrounding metamorphic gneiss complexes (Ansdell, 2005). REE patterns (Fig. 9) of the THO plutonic rocks show a large LREE enrichment and moderate HREE depletion. Volcanic rocks have two patterns, a flat REE pattern that is very enriched, and another that exhibits a moderate LREE enrichment and a relatively flat HREE slope.

1.3.2.2 Penokean Province

The Penokean province is another section of juvenile crust characterized by igneous and metasedimentary rocks in an east-northeast-trending Paleoproterozoic belt (Whitmeyer and Karlstrom, 2007). Proterozoic rocks of the region range from gabbro or diorite through granodioirite to granite with calc-alkaline to alkaline affinities (Sims et al., 1993). Volcanic suites are very abundant within the Penokean orogenic terranes, consisting of rhyolite, andesite and basalt (Sims et al., 1989). Limited geochemical data exist for 1.9 –1.8 Ga rocks in the Penokean province. REE data for granitoids and volcanics within the region (Fig. 10) are summarized from Sims et al. (1989) and Sims et al. (1993).

1.3.2.3 NW Cananda Terranes

The northwest Canada terranes consist of the Wopmay Orogen, Great Bear Magmatic Zone, and other tectonic elements which make up the Paleoproterozoic juvenile terranes of the region (Hoffman, 1988). The region is lithologically characterized by granitiod to gabbroic rocks, volcanics, and metamorphic gneisses (Lalonde and Bernard, 1993), similar to that of the Trans-Hudson Orogen. Limited whole-rock trace element geochemistry exists for this regions, so it is assumed that these lithologic units have similar trace element geochemistry as the Trans-Hudson orogeny. Lalonde and Bernard (1993) have noted of periluminous plutonism in the region.

1.3.3 1.2 – 0.8 Ga Provinces

The youngest of the distinct age populations, 1.2 – 0.8 Ga, has two potential source provinces, the Grenville province (1.2 – 0.8 Ga) and/or the Midcontinent Rift system (~1.1 Ga). Both regions are thought to source certain samples within the Ordovician midcontinent (Pickell, 2012; Ibrahim; pers. comm. 2015). These two provinces are characterized by very different rock types because of their respective tectonic evolution. To aid in provenance discrimination, both provinces are geochemically described below.

1.3.3.1 Grenville Province

The Grenville province, a north-east trending orogen situated proximal to the Superior province, is dominated by granitoid and metaplutonic rocks (McLelland et al., 2010). Granitic intrusions developed during the Grenville Orogeny are unusually Zr-enriched and erosion of these plutonic source rocks generate large volumes of detrital zircons (Moecher and Samson, 2006). These granitoid suites are typically A-type (Gorring et al., 2004) in compositional affinity. Compiled geochemical data from granitoid rocks of the Grenville province have a whole-rock REE pattern (Fig. 11A) that exhibit a moderate LREE enrichment, moderate HREE depletion, moderate to large Eu anomaly, and no Ce anomaly. The calculated zircon/chondrite REE pattern (Fig. 11B) consists of a relatively flat LREE slope, HREE enrichment, and a large -Eu anomaly.

1.3.3.2 Midcontinent Rift System

The Midcontinent Rift (MCR), approximately 2300 km long, is dominated by tholeiitic flood basalts and gabbroic rocks, with silicic magmatism being locally significant because of regional tectonic subsidence (Green, 1983; Vervoort et al., 2007). Compiled geochemical data from the mafic gabbro rocks of the MCR have a whole-rock REE (Fig. 11A) pattern that has a relatively flat REE pattern with a slight enrichment of LREE relative to HREE. The calculated zircon chondrite REE pattern (Fig. 11B) consists of a LREE depletion, HREE enrichment, and large positive Ce anomaly. An additional zircon/chondrite pattern is used for provenance discrimination, zircon standard FC-1, which is from the Duluth Gabbro complex of the MCR and also a reference standard used in this study. FC-1 exhibits a similar REE pattern but has a large -Eu anomaly.

2. METHODS

2.1 Sample Preparation

Samples analyzed in this study were processed previously for U-Pb dating in the mineral separation lab at Texas A&M University using standard bulk rock crushing techniques with the jawcrusher, followed by disc milling. A Wilfley table was then used to concentrate zircon grains into a heavy minerals collection, and subsequent heavy liquid separation was performed using methylene iodide (MEI). Grains were then handpicked and mounted into a 1" diameter epoxy puck. As these samples were prepped in previous work for U-Pb analyses, each sample epoxy puck was altered by removing previous reference standards with the exception of NIST SRM 610, and new reference standards (Harvard zircon 91500, Peixe, FC-1, and NIST SRM 612) were re-mounted into each puck to use for trace element analyses. Further details about sample preparation, sample analysis and data reduction conducted in the U-Pb analyses are in Pickell (2012).

2.2 Trace Element Method Development

The Radiogenic Isotope Laboratory at Texas A&M University houses a ThermoElectron ElementXR™ high resolution sector-field ICP-MS coupled with an ANALYTE.G2 excimer laser with 193 nm wavelength and 5ns pulse length. Because this is the first zircon laser-ablation trace element study conducted in the lab, a detailed description of trace element analytical protocols, following largely after the LA-ICPMS methods described by Kylander-Clark et al. (2013) and Yuan et al. (2008) is presented.

Twenty-four isotopes (^{29}Si, ^{49}Ti, ^{89}Y, ^{91}Zr, ^{93}Nb, ^{139}La, ^{140}Ce, ^{141}Pr, ^{146}Nd, ^{147}Sm, ^{151}Eu, ^{153}Eu, ^{157}Gd, ^{159}Tb, ^{163}Dy, ^{165}Ho, ^{166}Er, ^{169}Tm, ^{172}Yb, ^{175}Lu, ^{179}Hf, ^{181}Ta, ^{232}Th, ^{238}U) were analyzed. Each analysis acquires an average of 30 s background (blank duration) followed by 30 s of data collection (ablation duration).

During method development, data were calibrated using NIST SRM 610 as the external calibrant, using ^{29}Si as the internal elemental standard, treating 91500 as an unknown to validate the method. Data reduction was performed offline using an in-house Excel® data reduction program which follows the procedures of Longerich et al. (1996) to calculate elemental abundances and their uncertainties, as well as corrections for instrument drift and matrix-induced fractionation between NIST standards and zircon standards. NIST SRM 610 concentration values are from Jochum et al. (2011). Quantification of NIST SRM 610 values were compared to Harvard zircon 91500 to optimize analytical protocols and machine parameters.

2.3 Sample Analysis

During sample analysis, external calibration was conducted with Harvard zircon 91500, using ^{29}Si as the internal elemental standard. Harvard zircon 91500 served as the primary, with FC-1 and Peixe serving as secondary zircon standards. NIST SRM 610 was used to check elemental signal intensity during each analysis. Using back-scattered electron (BSE) images to create a grain numbered map of each sample set, the same zircon grains that were previously analyzed were ablated again with a second spot. As variation in internal texture exists within zircon (Corfu et al., 2003), cathodoluminescense (CL) images from previous studies were used to help analyze as closely as possible to the same CL zonation of the previous U-Pb analysis. Samples were analyzed with instrument parameters including a laser frequency of 10 Hz, laser fluence of 4.95 J/cm^2, and ablation spot size of 40 µm. Standard grains were analyzed between sets of 7-8 unknown sample zircons.

2.4 Sample Size

Previous U-Pb analyses averaged 120 zircon grains per sample. As the aim of this study is to differentiate similar age source regions, analyses for a smaller, targeted subset consisted of approximately 50 zircon grains. For data results of a sample to be representative of the overall zircon population, an adequate statistical number of grains and an aspect of randomness needs to be incorporated to reduce sample bias (Fedo et al., 2003; Vermeesch, 2004). Because not all grains of previous populations were analyzed, a target of 50 grains within the age ranges of 1.2 -0.8 Ga, 2.4 – 1.8 Ga, and ≥2.5 Ga were selected for analysis. Previous U-Pb data reduction used a 50 Ma age bin for histogram plots, and the same age bin was used to select a proportional number of grains of each bin to have an adequate sample representation. Larger grains were preferentially picked for this work because it is necessary to fit a second ablation spot on the same grain, and within the same CL zone, potentially leading to some degree of sample bias (e.g. Malusa et al., 2013).

2.5 Geochemical Database

In order to demonstrate the variability of rock types within sediment source regions, which should be reflected in the variability of trace element characteristics in detrital zircons, a geochemical database was built containing trace element values from potential source provinces. The EarthChem Portal (hosted at the Lamont-Doherty Earth Observatory, Columbia University) offers integrated access to geochemical data from around the globe. Utilizing this resource, data were collected using search criteria such as age, location, and chemistry. For each potential source province, a compiled database was made to evaluate geochemical variation(s) of potential detrital zircon source rocks. Additional geochemical data was also incorporated from various studies in the case of the EarthChem Database lacking geochemical data. REE plots were normalized using McDonough and Sun (1995) chondrite values.

3. RESULTS

The results of this study are presented in two parts. First, the method development results of reference standard Harvard zircon 91500 and secondary standards, Peixe and FC-1, compared to published values. Second, the zircon trace element data from analyzed samples are presented in chondrite-normalized REE plots, and various discrimination diagrams which allow chondrite-normalized patterns to be evaluated (Belosouva et al., 2002): 1) Ce/Ce* vs. Eu/Eu*, where Eu is the chondrite-normalized Eu concentration and Eu* is the average of the chondrite-normalized Sm and Gd concentrations, and Ce is the chondrite-normalized Ce concentration and Ce* is the average of the chondrite-normalized La and Pr values; 2) Nb vs. Ta, both in terms of elemental abundance (ppm); 3) Y vs. U, both in terms of elemental abundance (ppm).

3.1 Method Development Results

Using the analytical protocols described above, a composite plot of zircon standards 91500, Peixe, and FC-1 was made for comparison to previously published values (Fig. 12; Table 1). Peixe and FC-1 standards were analyzed as unknowns against the 91500 primary external standard and interspersed with the unknown detrital zircon analyses. The consistency of these secondary standards with published values, and the resolution of the two distinctly different patterns indicate the ability of this method to resolve trace element characteristics in detrital zircons. Trace element concentrations in several 91500 analyses were calculated using other analyses of 91500 as the external standard to give an indication of the reproducibility of the analytical method both throughout the course of an analytical session and from session-to-session. These data reinforce the applicability of the analytical methods for zircon trace element characterization.

3.2 Detrital Zircon Geochemistry

Trace element concentrations in detrital zircons from the 8 analyzed samples from the western margin and midcontinent are plotted in Figures 13-20. Results of this dataset indicates that all 8 samples share, to a large extent, the following common characteristics:

1) A majority of grains, regardless of age, have a consistently similar REE pattern with a LREE depletion, large Ce anomaly, moderate to large Eu anomaly, and HREE enrichment.
2) Ce/Ce* vs. Eu/Eu* values for the majority of grains cluster together outside the range of values representative of common granitoid compositions, and are more consistent with highly alkaline rocks (e.g. syenite).
3) Nb vs. Ta values demonstrate a linear trend between the three different age groups. 1.2-0.8 Ga zircons are more enriched in Nb and Ta indicating a more felsic melt composition, >2.5 Ga zircons typically have a more-mafic melt composition, and 2.4-1.8 Ga zircons display a larger degree of variation.
4) Y vs. U values for all grains cluster together in no consistent pattern and they lack any clear spread in values, in contrast to those of Belousova et al. (2002).

With the exception of samples from the Morberly Mountain section, a small number of detrital zircons in each sample show considerable deviation from the consistent REE pattern that is prevalent in all samples. Below are descriptions of sampled zircons with atypical characteristics.

3.2.1 Bear Lake Section

Lower (BL4) and Upper Bear Lake (BL6) Archean zircons from the western margin both exhibit atypical zircon REE patterns. BL6 has three atypical detrital zircon REE patterns (Fig. 17), with U-Pb ages of 3.94, 2.77, and 2.71 Ga, which have very similar REE patterns consisting of a LREE depletion, small to moderate Ce anomaly, small -Eu anomaly, and a somewhat concave HREE. BL4 has two similar atypical zircon REE signatures (Fig. 16) compared to BL6, with ages of 2.70 Ga and 2.69 Ga.

3.2.2 St. Peter Section

The Lower St. Peter (S5) section contains four atypical zircons with two main zircon REE patterns (Fig. 18): 1) S5_50 And S5_51 have a similar HREE slope and Eu anomaly compared to the dominant pattern, but with a higher enrichment in the LREE; 2) S5_28 And S5_44 have the opposite of the first two atypical grains of the sample, their LREE slope and Ce anomaly are nearly identical with the dominant pattern, but a slight -Eu anomaly and much flatter HREE slope. The Upper St. Peter (AS2) section detrital zircon REE patterns (Fig. 19) has a single 2.70 Ga zircon signature differentiable from the rest (AS2_27). The atypical REE pattern has similar La and Ce chondrite-normalized values to the dominant zircon pattern, but higher enrichment in the rest of the LREE, little to no Eu anomaly, and a low positive HREE slope.

3.2.3 Calico Rock Section

Basal Calico Rock (BC) and Top Calico Rock (CR) have more zircons with atypical REE patterns compared to other sections (Figs. 20-21). Both BC and CR have a two zircons with similar REE pattern to the Lower St. Peter section (purple lines), all being Archean with the exception of CR_22 having a U-Pb age of 1.01 Ga. BC has two additional atypical REE patterns: 1) BC_21 has a nearly identical LREE and Eu anomaly to the dominant patterns but with a nearly flat HREE slope, comparable to high-pressure gneisses (Hermann et al., 2001); 2) BC_6 has a LREE depletion, large Ce anomaly, and a HREE enrichment with a subtle concave pattern; commonly occurs in mafic igneous zircons (see Fig.7). Sample CR has an additional 5 atypical REE patterns: 1) CR_19, 2) CR_17, 3) CR_1 and CR_6, 4) CR_11, and 5) CR_14. All of which have a LREE depletion, a varying Ce anomaly size, and a moderate, positive HREE slope except for CR_17 which has a relatively flat HREE slope. All of these analyses also have varying Eu anomalies.

4. DISCUSSION

The results of these analyzes are most readily divided into 2 groups; those with "*typical*" and "*atypical*" geochemical signatures. Typical detrital zircons are the dominant population in all 8 samples. Atypical detrital zircons have REE patterns which clearly vary from those of typical zircons. The sections below outline and speculate on what governs the geochemical characteristics of typical and atypical grains, and how the results of these two groups can or cannot be used to constrain sediment provenance.

4.1 "*Typical*" REE Patterns

It is well documented that trace element signatures in zircon can reflect aspects of their origin and petrogenesis (Belousova et al., 2002; Rubatto, 2002) and early studies indicated that petrogenetic variation occurs between and within the Transcontinental Proterozoic provinces (Van Schmus et al., 1993). Thus, geochemical signatures in detrital zircons sourced from Laurentian provinces are anticipated to serve as an additional discrimination tool for sediment provenance. However, trace element discrimination diagrams for detrital zircons from all 8 samples yielded very similar patterns. The bulk of detrital zircon analyses do not show clear, differentiable geochemical characteristics that can be correlated with the changes in provenance inferred from the age spectra.

This study originally centered on the hypothesis that similar-age Archean and Proterozoic provinces of Laurentia with rocks of different trace element geochemical signatures should impart different signatures into the zircons derived from those rocks. However, results show no clear distinction between groups of detrital zircons, raising the questions: 1) Do zircons from different rock types necessarily record geochemical differences? 2) Are trace elements in detrital zircons from the quartz arenites being measured accurately and precisely enough to be resolvable? 3) Do changes in provenance not result in resolvable changes in the chemistry of the detrital zircon population because the rocks themselves in the different source regions do not vary much? 4) Is there a hidden “bias” that is caused by a dominant lithology within the source regions?

Geochemical signatures for the three zircon standards show variation in trace-elemental composition compared to one another, indicating that trace elements in zircon can be measured analytically and that variations can be resolved because each zircon has different origin and petrogenesis. Zircons in general record geochemical differences based on their crystallization environment and geologic processes (Belousova et al, 2002) and can be determined in detrital zircons as well (e.g. Barth et al., 2013). Atypical detrital zircons in this study also have a large variation in geochemical signatures, which serves to further support the claim that the analytical methods can discriminate between zircons from different rock types.

Hoskin and Ireland (2000) showed that detrital zircons in their study, much like this one, showed a narrow range of abundances and little systematic difference between REE patterns. Their results were supported by experimental studies (Hanchar et al, 2000) which indicated coupled-substitution limitations on REE concentrations in zircon can be the main mechanism responsible for the typical REE patterns. The limitations of REE substitution into the zircon crystal lattice is driven by an abundance of phosphorus

(P^{5+}) substitution into the crystal lattice which limits the amount of HREE substitution for Zr^{4+}, with LREE substitution being severely limited because HREE have larger ionic radii more closely matched to Zr^{4+}. It appears that the geochemistry for the majority of the typical detrital zircons is governed by the coupled-substitution mechanism rather than by K_d.

Previous U-Pb analyses for samples in this study were interpreted to indicate a considerable shift in provenance based on comparisons of age spectra. However, trace elements do not indicate (or cannot resolve) any significant change in rock composition, within the "*typical*" zircons that represent the bulk of the analyses.

4.2 "*Atypical*" REE Patterns

Detrital zircons with "*atypical*" geochemical characteristics occur within the Bear Lake, St. Peter, and Calico Rock sections (Fig. 21). Variations exist between these atypical signatures which indicate that different rock types may be sourcing each sample location. The REE patterns of atypical grains closely resemble REE patterns of hydrothermal (Coogan et al., 2006) and metamorphic zircons (Hermann et al., 2001). Unfortunately, the trace element characteristics of zircons of metamorphic or hydrothermal origin cannot be readily tied to variations in rock types in a way that would be a useful provenance indicator. This is primarily due to the fact that the trace element characteristics of the rocks, and the factors that control element partitioning into zircon, are poorly characterized.

The presence of atypical zircons in addition to the typical zircons shows plausible reason to state that trace element discrimination methods can be used to differentiate zircons of drastically different rock type. However, the inability to discriminate typical zircons from one another and that atypical zircons are hydrothermal, metamorphic, and unknown in origin involving complex petrogenesis leads to large uncertainty in correlations being made to source regions and inadequate to aid in constraining sediment provenance.

5. CONCLUSIONS

Samples analyzed in this study indicate that geochemical variations in zircon may not always be unique, but rather populations may be similar because of the petrogenesis of zircon-dominated crustal rocks and the coupled-substitution limitations on REE into the zircon crystal lattice. This study concludes that trace element discrimination of detrital zircons is hindered by REE coupled-substitution limitations and therefore, at least in the case of the Middle Ordovician quartz arenites, does not provide a good measure by which to constrain sediment provenance. This study shows that some variation in detrital zircon geochemical signatures do occur (e.g. Bear Lake, St. Peter, and Calico Rock samples), however the majority of geochemical signatures for the Archean, Paleoproterozoic, and 1.2 – 0.8 Ga zircons are not differentiable from one another, and atypical zircons do not provide further aid to sediment provenance other than some atypical grains have comparable patterns that may indicate rock type.

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APPENDIX A

FIGURES

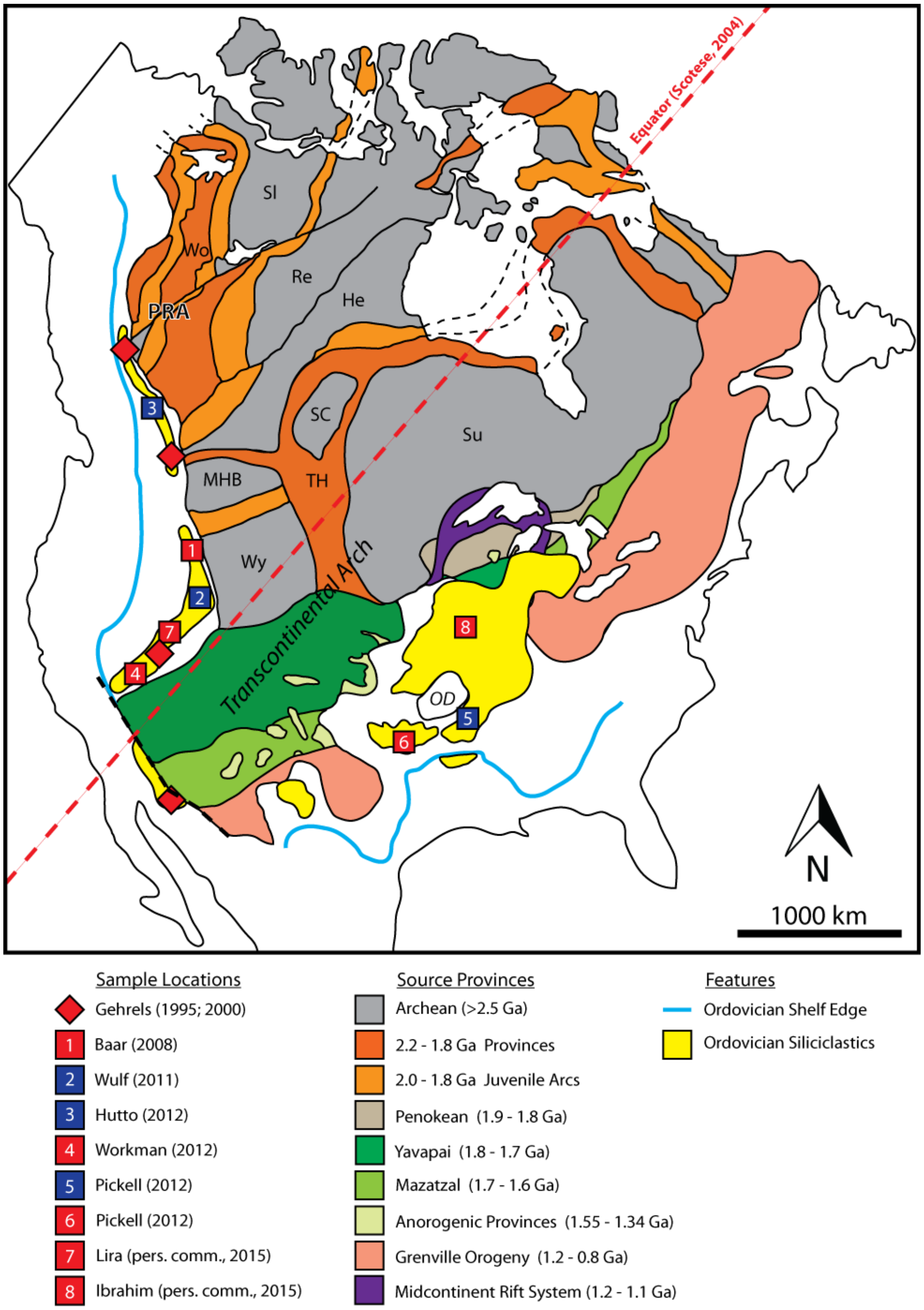


Figure 1. North American map with locations of Ordovician samples relative to crustal provinces. PRA- Peace River Arch region; Wy- Wyoming province; MHB- Medicine Hat Block; Su- Superior province; TH- Trans-Hudson orogen; SC- Sask Craton; He- Hearne province; Ra- Rae province; Sl- Slave province; Wo- Wopmay orogeny; OD- Ozark Dome [Adapted from Ketner (1968); Whitmeyer and Karlstrom (2007); Gehrels and Pecha (2014)]

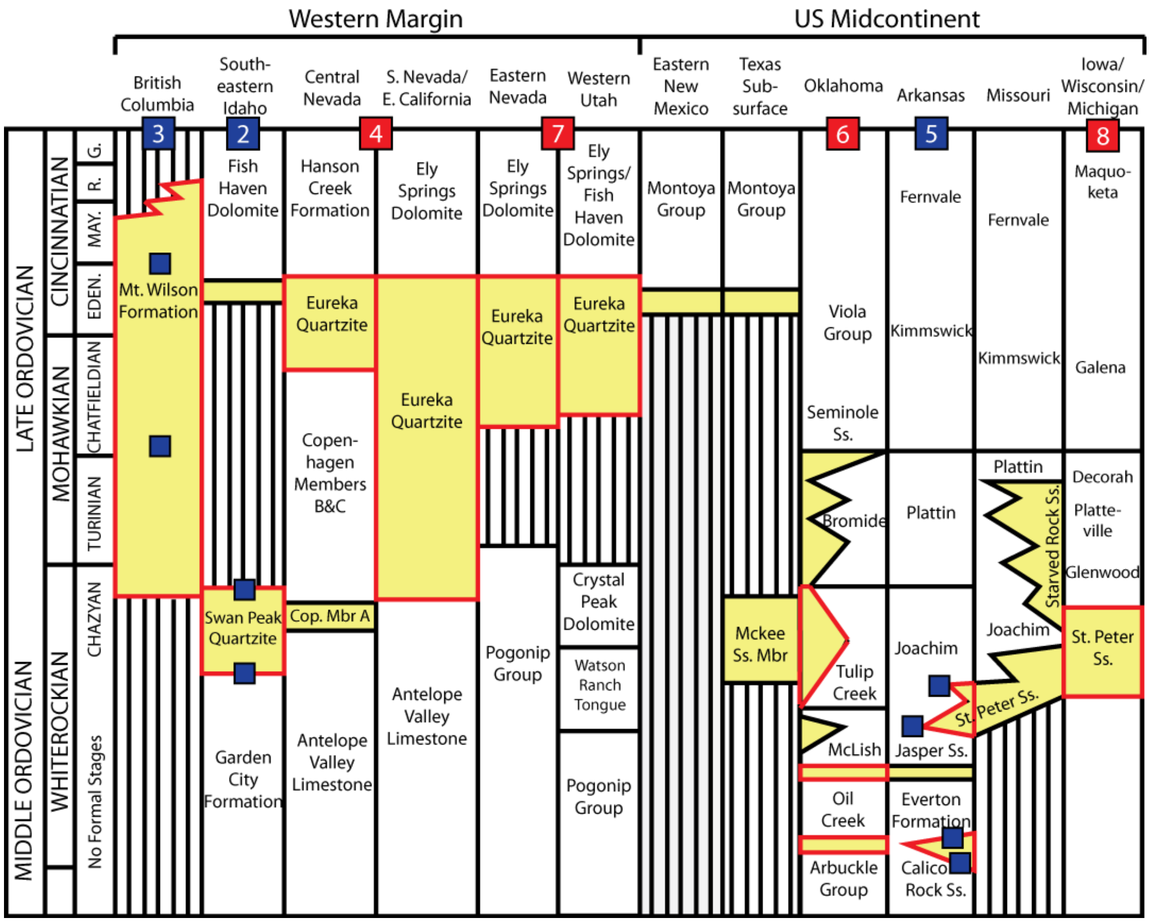


Figure 2. Chronostratigraphic chart of Middle-Late Ordovician units (yellow) of North America with units boxed in red to show units that have already analyzed for U-Pb ages by LA-ICP-MS. Numbers in boxes correspond to samples referenced in Figure 1. Blue boxes next to units indicate samples used in this study.

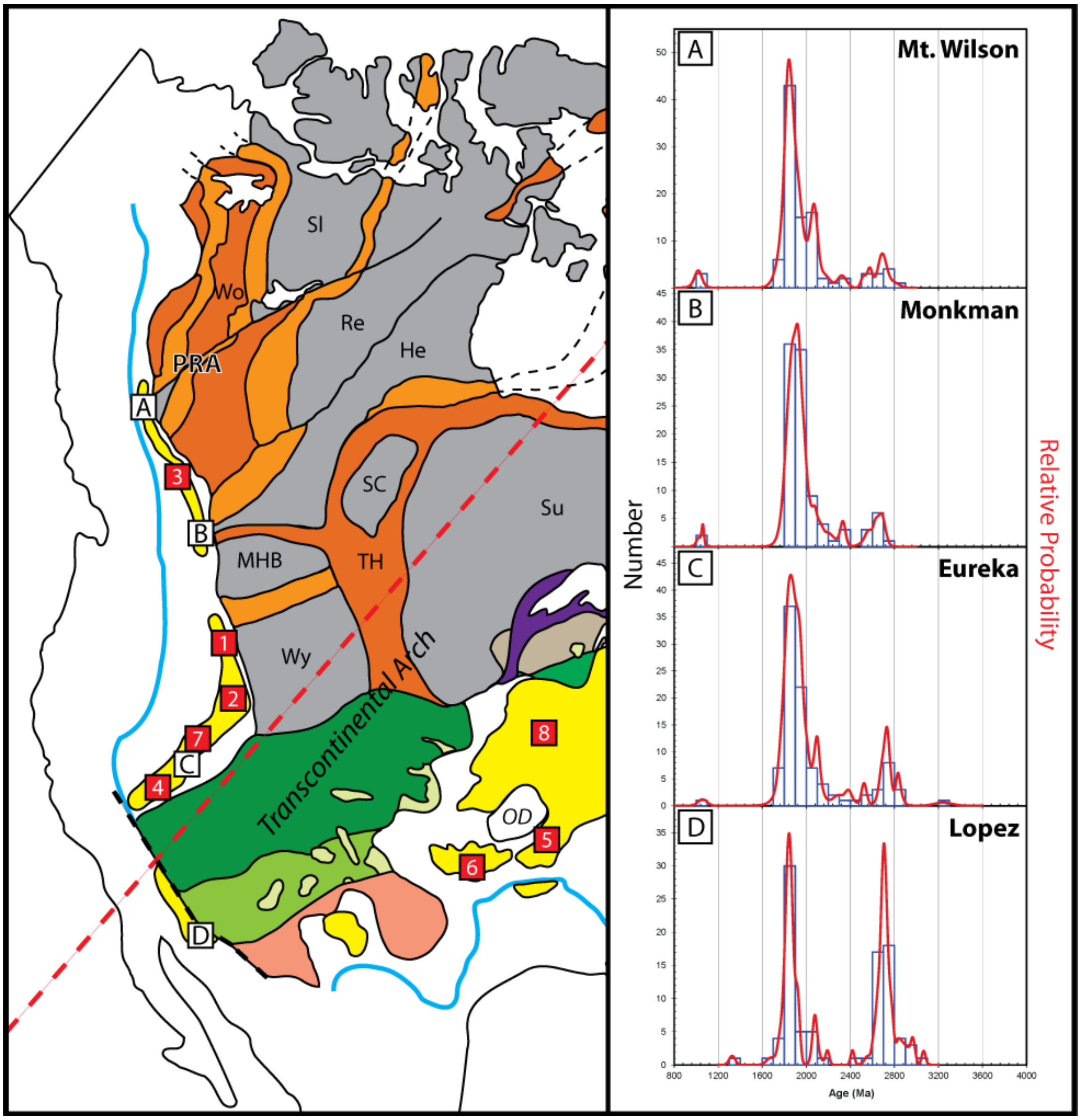


Figure 3. U-Pb probability density plots of 4 western margin samples (Gehrels, pers. comm. 2008) showing slight variations in provenance. Uncertainty arises to which province actually serves as the source because of the large geographic extent for provinces that are 2.4 – 1.8 Ga and Archean (>2.5 Ga) in age. Reference to Figure 1 for further map details.

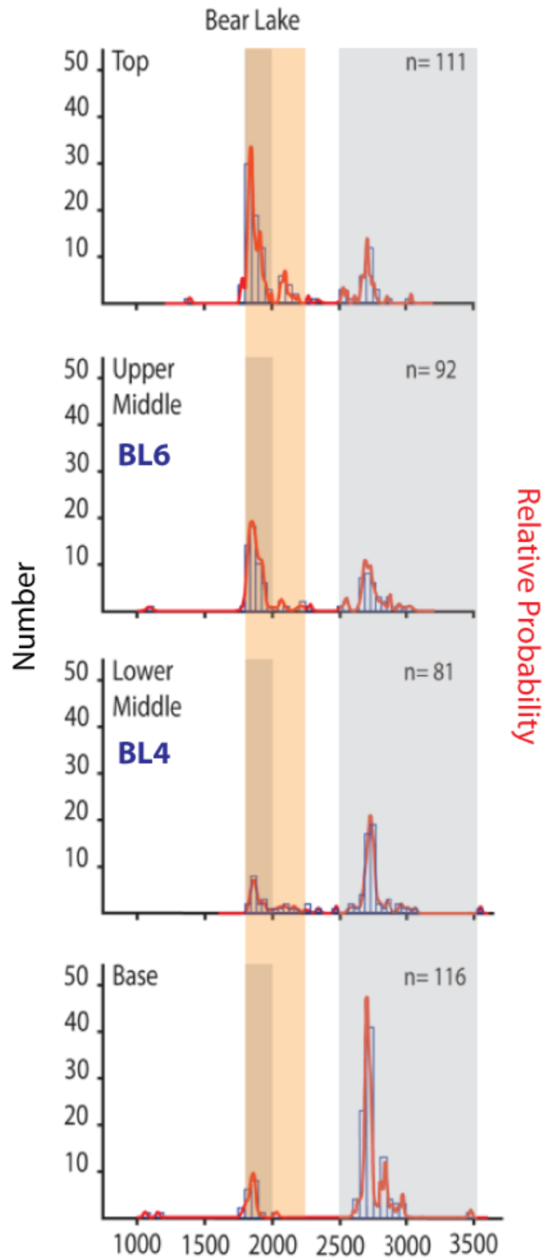


Figure 4. U-Pb histogram plots for the Swan Peak Quartzite, Idaho showing the most pronounced provenance shift of all previously analyzed Ordovician samples [modified from Wulf (2012)]. Samples BL6 and BL4 are used in this study.

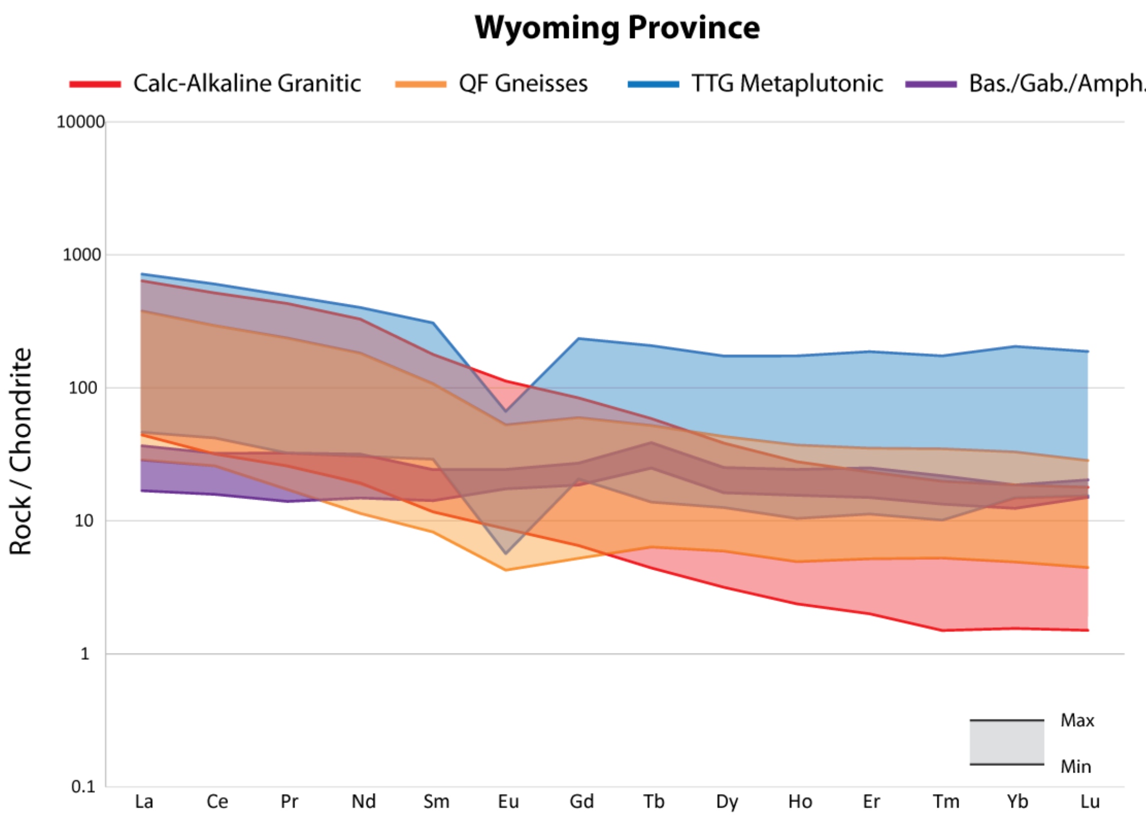


Figure 5. Whole-rock/chondrite REE plots for major lithologic units in the Wyoming Province. Data compiled from EarthChem Database. Chondrite values are from McDonough and Sun (1995).

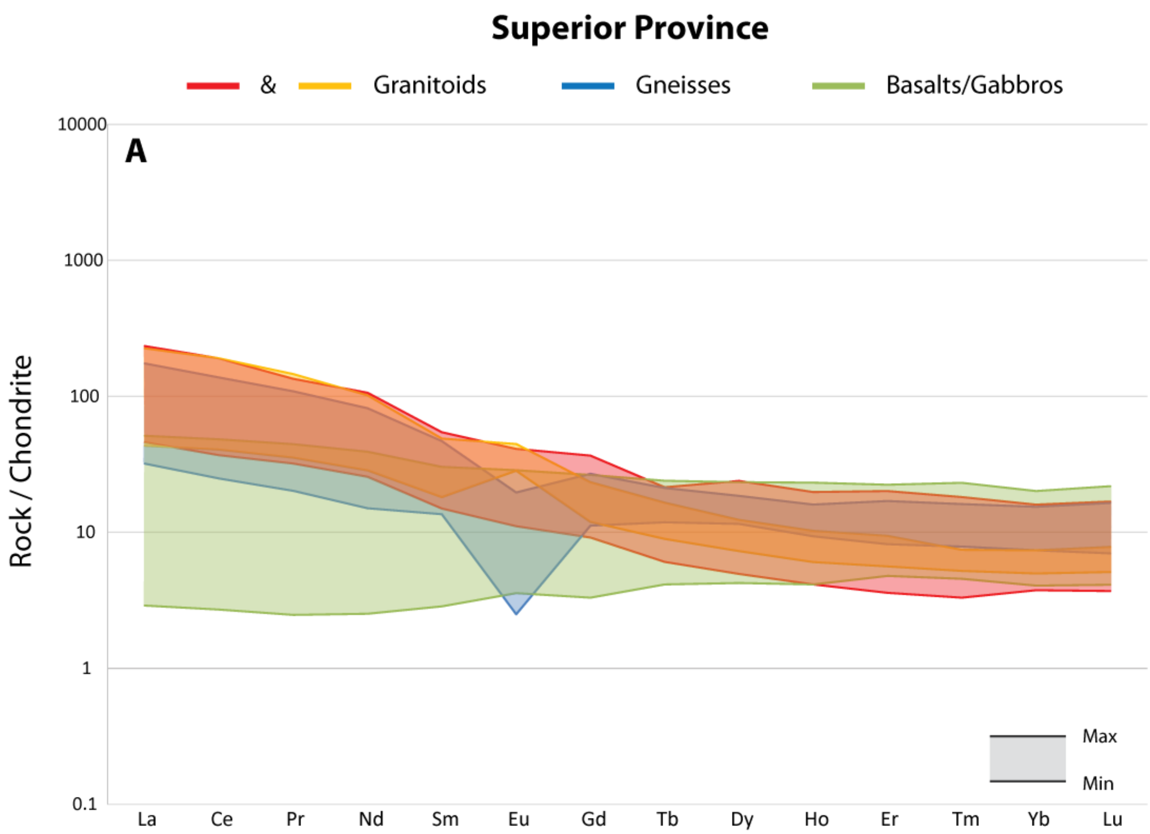


Figure 6. Whole-rock/chondrite REE plots for major lithologic units in the Superior Province. Data compiled from EarthChem Database. Chondrite values are from McDonough and Sun (1995).

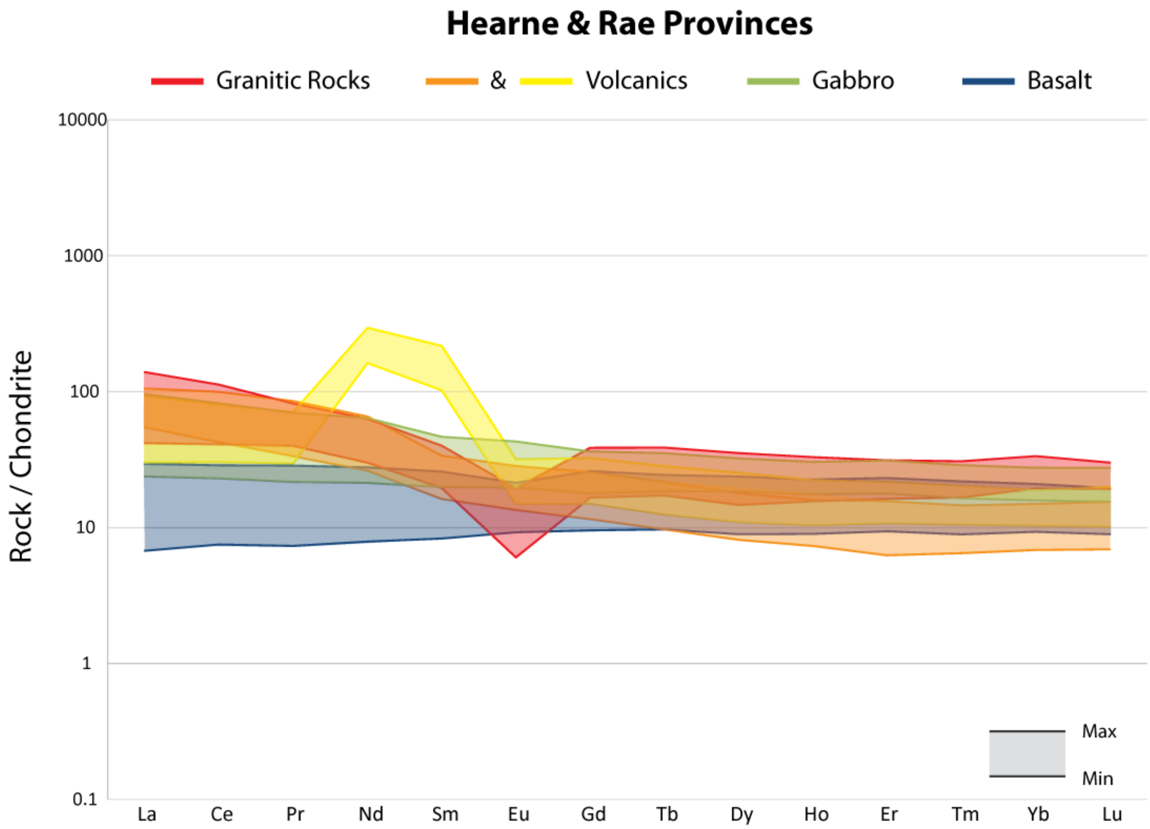


Figure 7. Whole-rock/chondrite REE plots for major lithologic units in the Hearne and Rae Provinces. Data compiled from EarthChem Database. Chondrite values are from McDonough and Sun (1995).

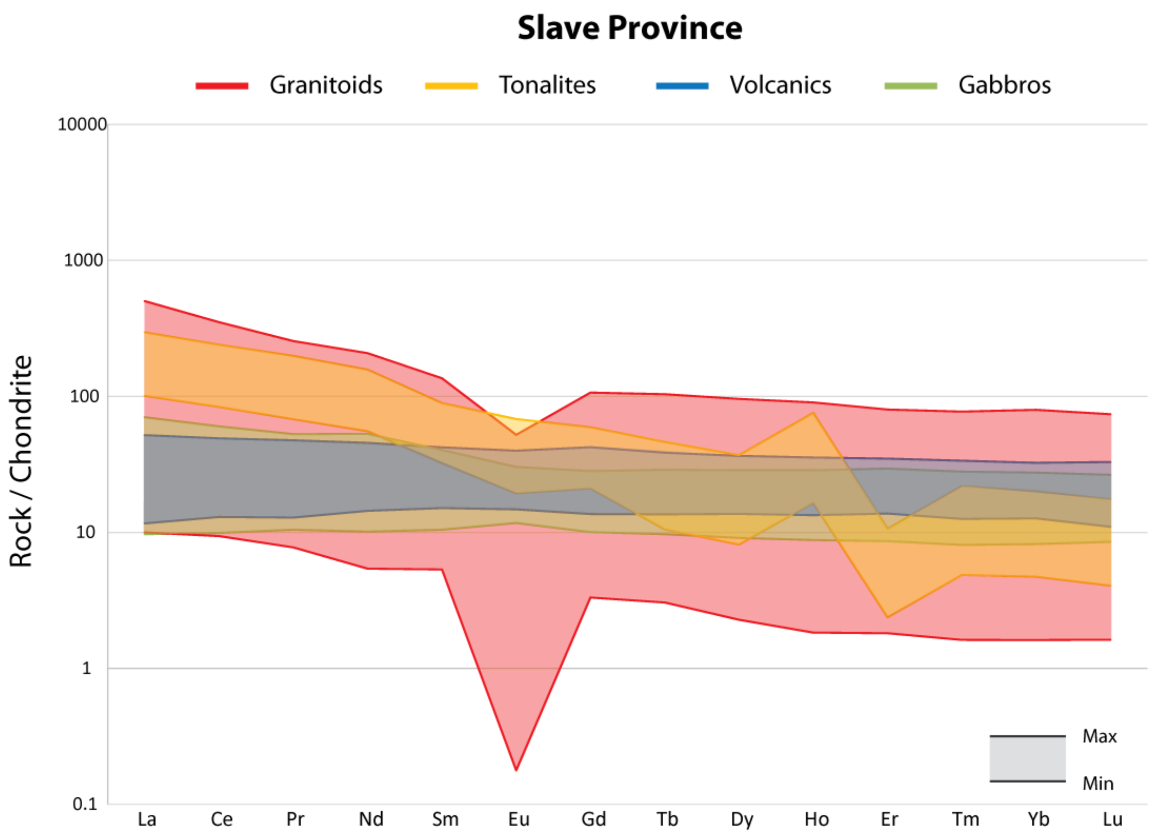


Figure 8. Whole-rock/chondrite REE plots for major lithologic units in the Slave Province. Data compiled from EarthChem Database. Chondrite values are from McDonough and Sun (1995).

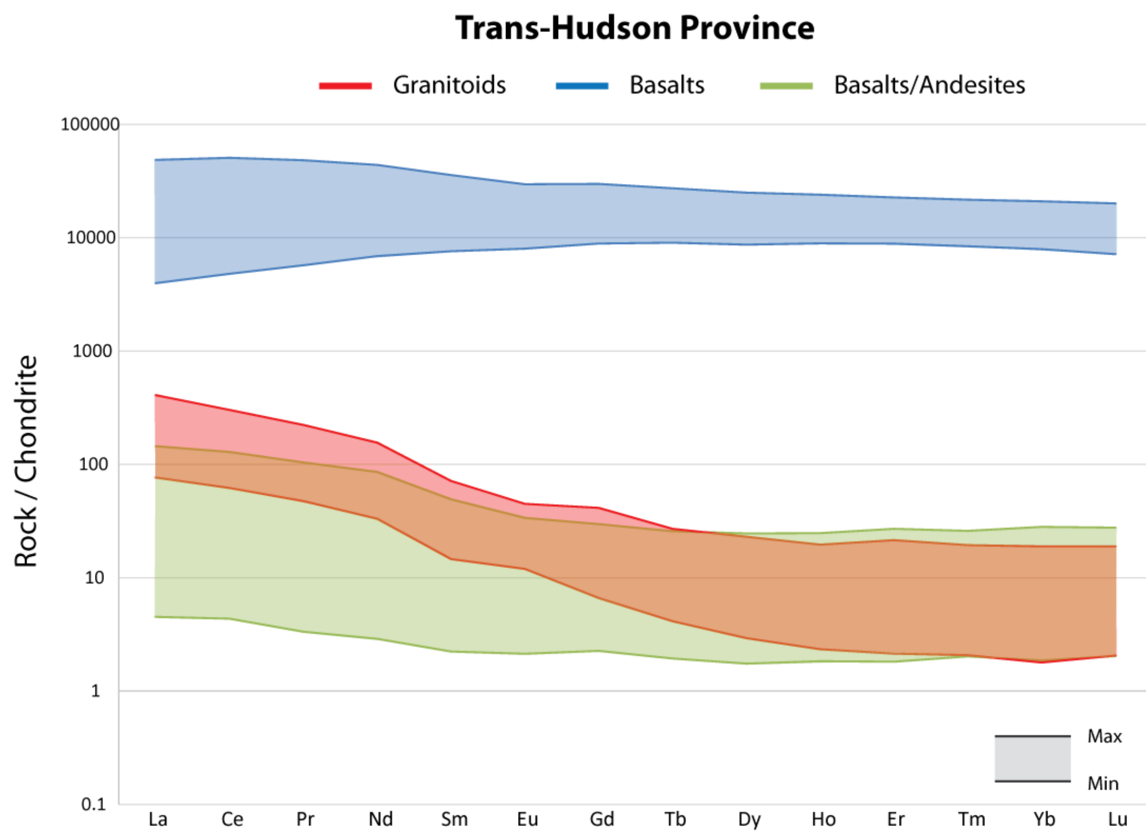


Figure 9. Whole-rock/chondrite REE plots for major lithologic units in the Trans-Hudson Province. Basalt, and basalt/andesites data compiled from EarthChem Database. Granitoid data compiled from MacHattie (2001). Chondrite values are from McDonough and Sun (1995).

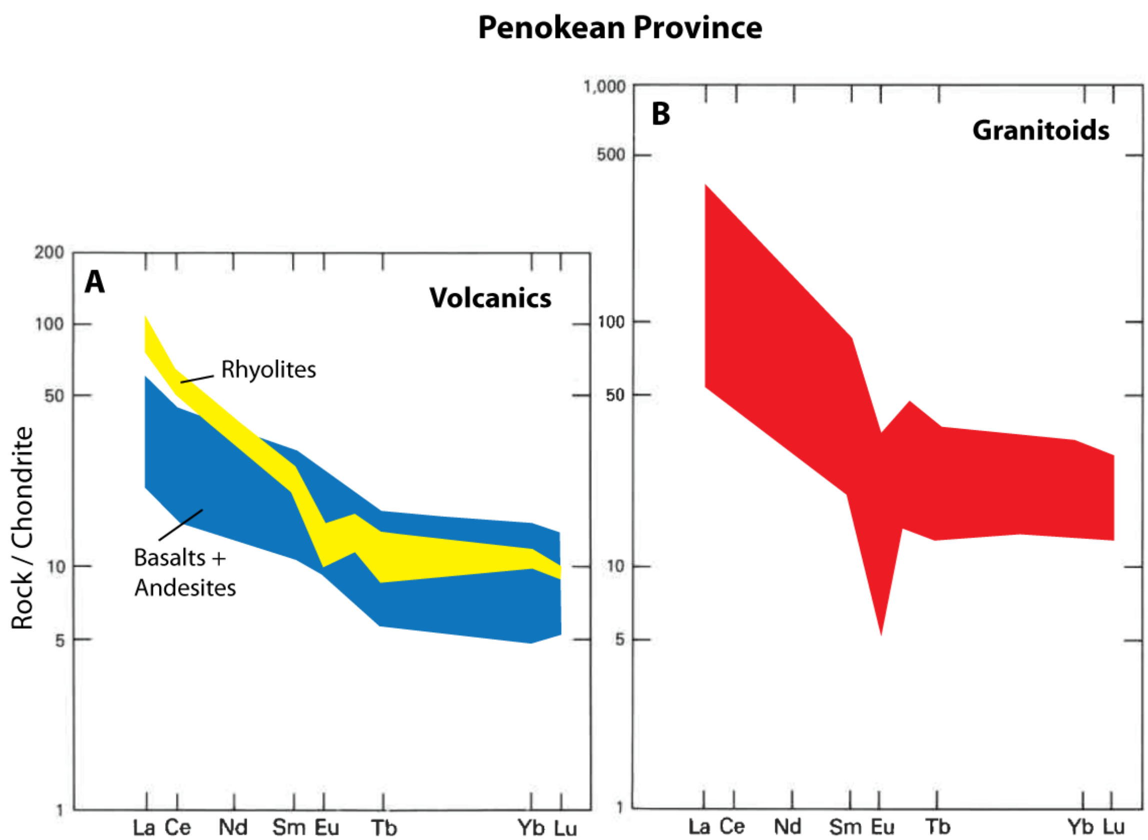


Figure 10. Whole-rock/chondrite REE plots for (A) volcanic and (B) granitoid rocks in the Penokean Province [modified from Sims et al. (1989)].

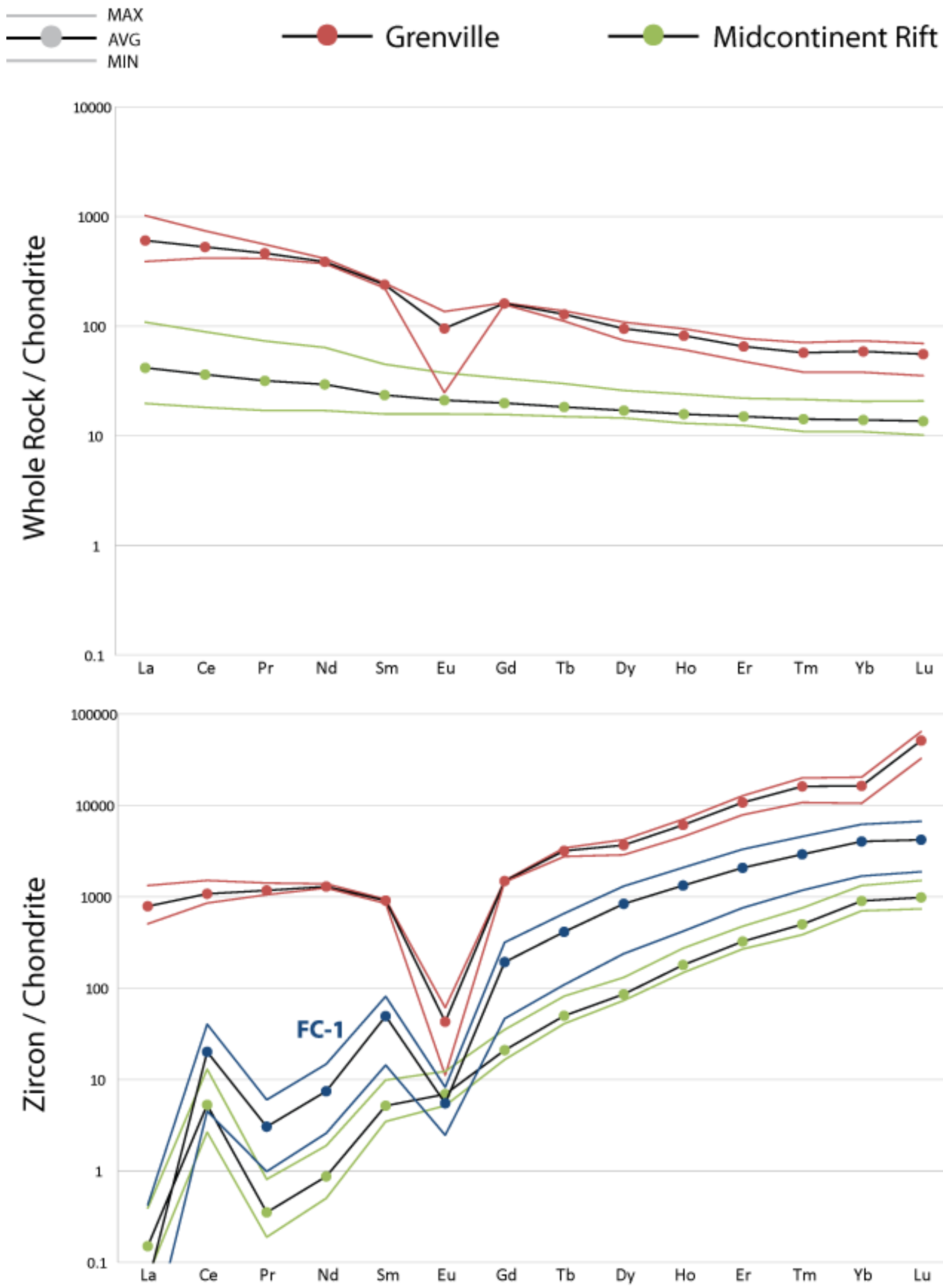


Figure 11. Whole rock (A) and zircon (B) chondrite-normalized REE plots showing the different anticipated zircon geochemical signatures of the Grenville (red) and Midcontinent Rift (green). Grenville granite geochemical data was compiled from Gorring et al. (2004) and Midcontinent Rift gabbro geochemical data was compiled from the EarthChem Database. Granite partition coefficients used to calculate anticipated zircon/chondrite values are from GERM Partition Coefficient Database (www.earthref.org) and gabbro partition coefficients were derived from geochemical data published in Kaczmarek et al. (2008). FC-1 data is compiled from all FC-1 analyses in this study.

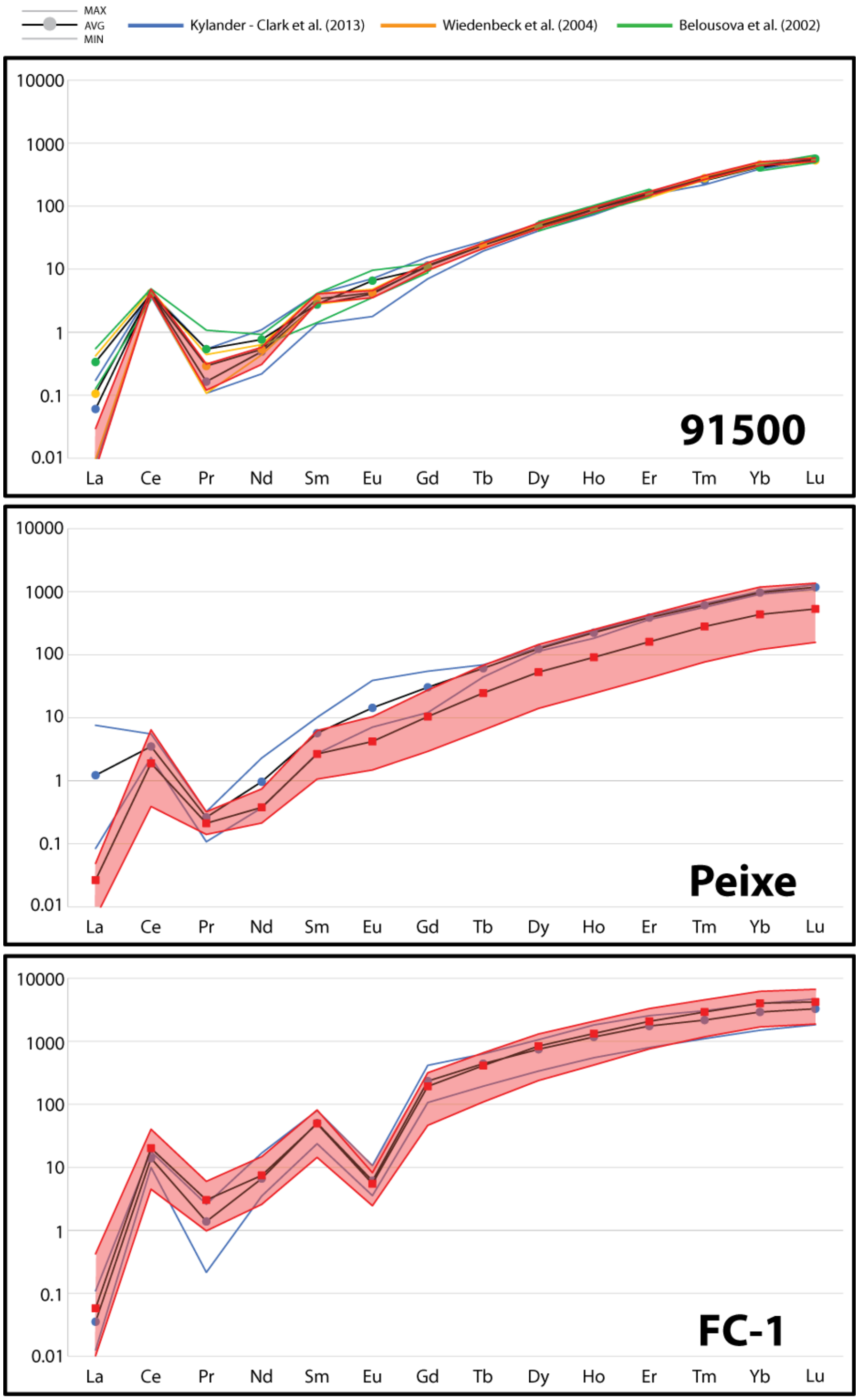


Figure 12. Zircon chondrite-normalized REE plots for the three reference standards used in this study (red outlines) compared to previously published values. 91500 served as the primary standard.

Figure 13. Zircon (A) chondrite-normalized REE plot, (B) Ce/Ce* vs. Eu/Eu*, (C) Nb vs. Ta, and (D) Y vs. U for the Moberley Mountain Lower sample. Chondrite values are from McDonough and Sun (1995). Fields for discrimination diagrams (B-D) based on distribution behavior in zircon according to the origin of their protolith are: 1) carbonatites; 2) kimberlites; 3) syenites; 4) mafic rocks; syenite pegmatites; 6) nepheline syenites and 7) granitoids [modified from Belousova et al. (2002) and Shchepetilnikova et al. (2015)].

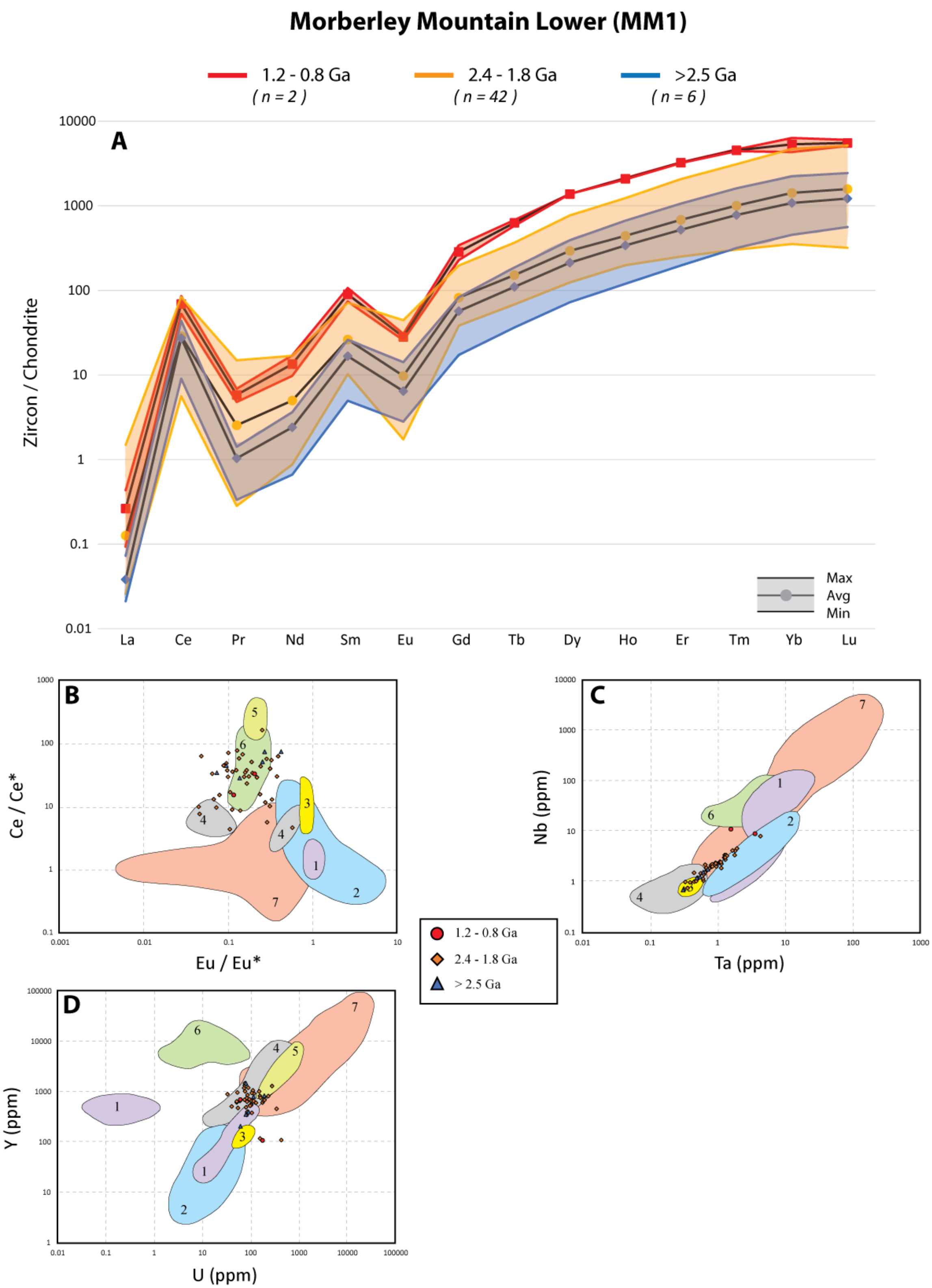
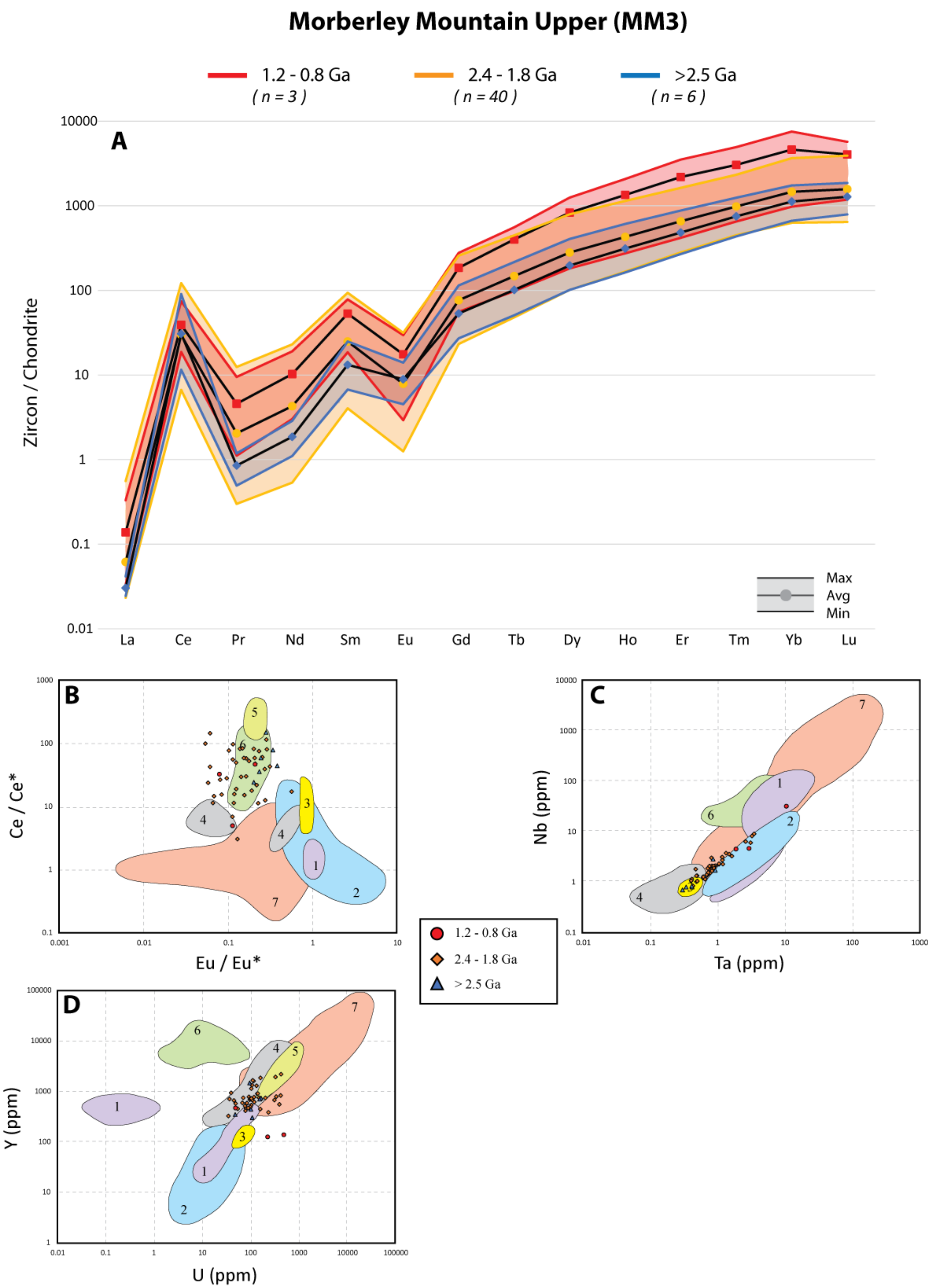

Morberley Mountain Lower (MM1)
1.2 - 0.8 Ga (n = 2)
2.4 - 1.8 Ga (n = 42)
>2.5 Ga (n = 6)
A
Zircon / Chondrite
La Ce Pr Nd Sm Eu Gd Tb Dy Ho Er Tm Yb Lu
Max
Avg
Min
B
Ce / Ce*
Eu / Eu*
C
Nb (ppm)
Ta (ppm)
D
Y (ppm)
U (ppm)
1.2 - 0.8 Ga
2.4 - 1.8 Ga
> 2.5 Ga

Figure 14. Zircon (A) chondrite-normalized REE plot, (B) Ce/Ce* vs. Eu/Eu*, (C) Nb vs. Ta, and (D) Y vs. U for the Moberley Mountain Upper sample. Chondrite values are from McDonough and Sun (1995). Fields for discrimination diagrams (B-D) based on distribution behavior in zircon according to the origin of their protolith are: 1) carbonatites; 2) kimberlites; 3) syenites; 4) mafic rocks; syenite pegmatites; 6) nepheline syenites and 7) granitoids [modified from Belousova et al. (2002) and Shchepetilnikova et al. (2015)].



Morberley Mountain Upper (MM3)
1.2 - 0.8 Ga
(n = 3)
2.4 - 1.8 Ga
(n = 40)
>2.5 Ga
(n = 6)
A
Zircon / Chondrite
10000
1000
100
10
1
0.1
0.01
La
Ce
Pr
Nd
Sm
Eu
Gd
Tb
Dy
Ho
Er
Tm
Yb
Lu
Max
Avg
Min
B
Ce / Ce*
Eu / Eu*
C
Nb (ppm)
Ta (ppm)
1.2 - 0.8 Ga
2.4 - 1.8 Ga
> 2.5 Ga
D
Y (ppm)
U (ppm)

Figure 15. Zircon (A) chondrite-normalized REE plot, (B) Ce/Ce* vs. Eu/Eu*, (C) Nb vs. Ta, and (D) Y vs. U for the Bear Lake Lower sample. Chondrite values are from McDonough and Sun (1995). Fields for discrimination diagrams (B-D) based on distribution behavior in zircon according to the origin of their protolith are: 1) carbonatites; 2) kimberlites; 3) syenites; 4) mafic rocks; syenite pegmatites; 6) nepheline syenites and 7) granitoids [modified from Belousova et al. (2002) and Shchepetilnikova et al. (2015)].

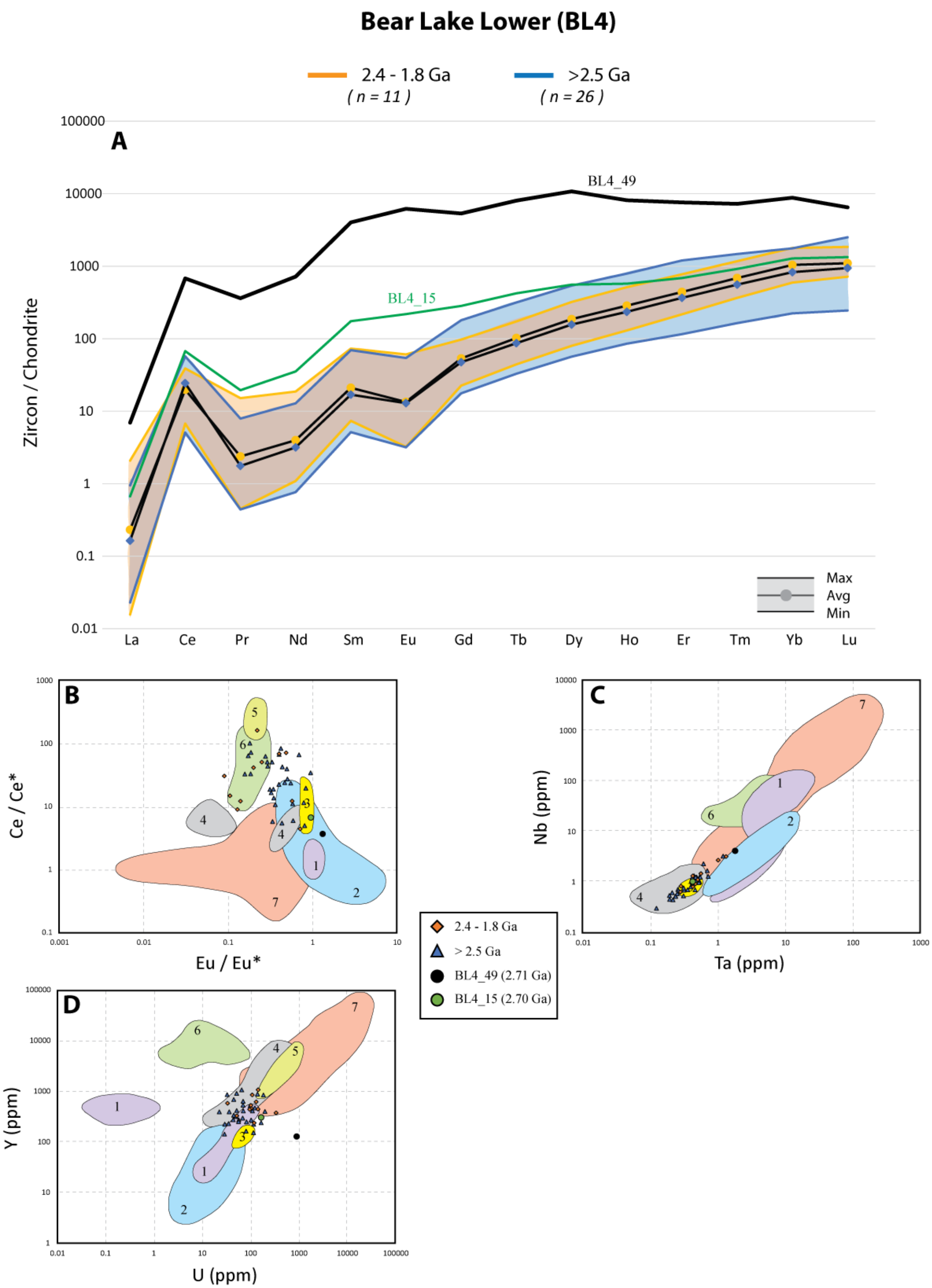
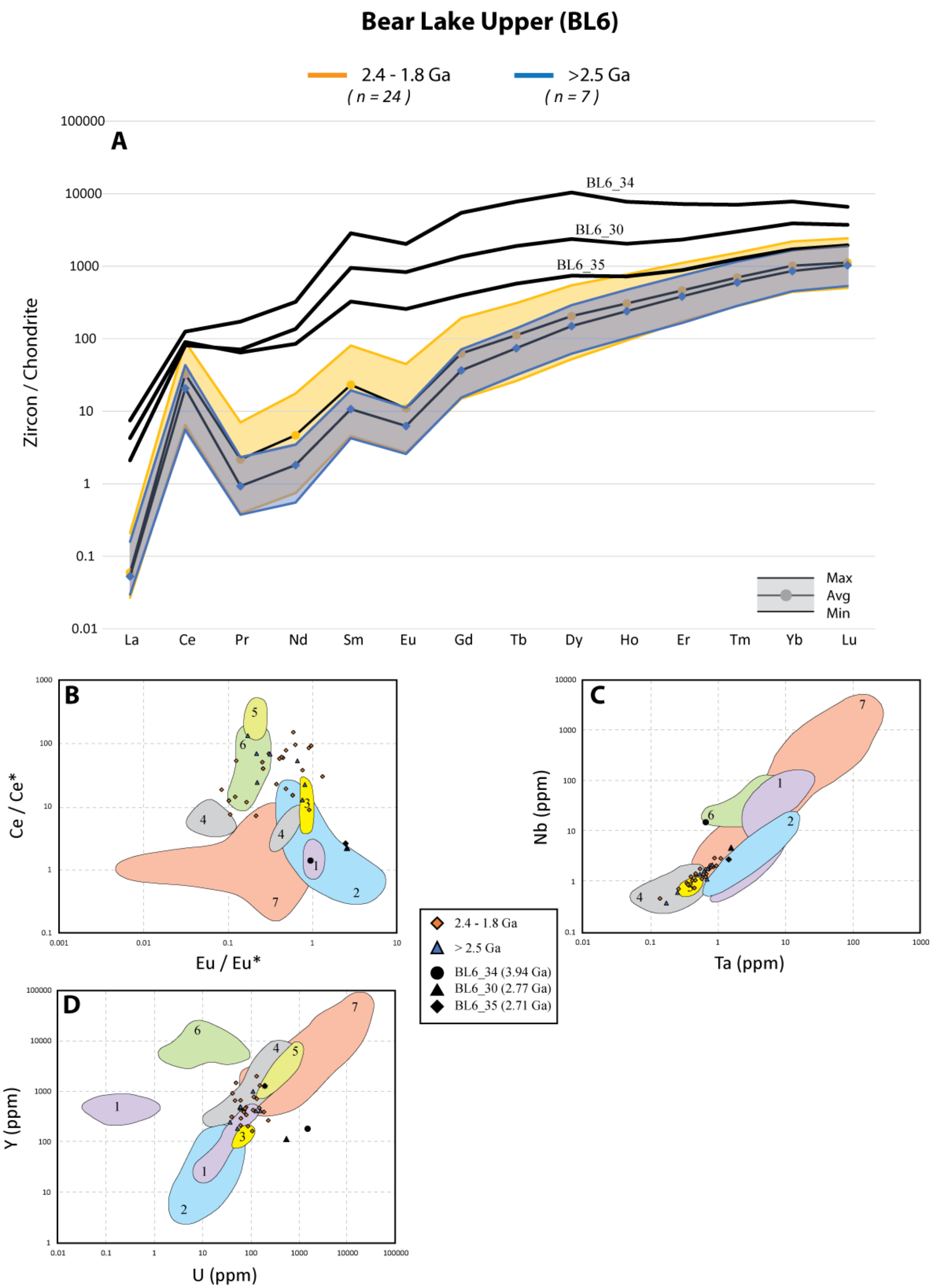

Bear Lake Lower (BL4)
2.4 - 1.8 Ga
(n = 11)
>2.5 Ga
(n = 26)
A
BL4_49
BL4_15
Zircon / Chondrite
Max
Avg
Min
La
Ce
Pr
Nd
Sm
Eu
Gd
Tb
Dy
Ho
Er
Tm
Yb
Lu
B
Ce / Ce*
Eu / Eu*
C
Nb (ppm)
Ta (ppm)
2.4 - 1.8 Ga
> 2.5 Ga
BL4_49 (2.71 Ga)
BL4_15 (2.70 Ga)
D
Y (ppm)
U (ppm)

Figure 16. Zircon (A) chondrite-normalized REE plot, (B) Ce/Ce* vs. Eu/Eu*, (C) Nb vs. Ta, and (D) Y vs. U for the Bear Lake Upper sample. Chondrite values are from McDonough and Sun (1995). Fields for discrimination diagrams (B-D) based on distribution behavior in zircon according to the origin of their protolith are: 1) carbonatites; 2) kimberlites; 3) syenites; 4) mafic rocks; syenite pegmatites; 6) nepheline syenites and 7) granitoids [modified from Belousova et al. (2002) and Shchepetilnikova et al. (2015)].



Bear Lake Upper (BL6)
2.4 - 1.8 Ga
(n = 24)
>2.5 Ga
(n = 7)
A
Zircon / Chondrite
BL6_34
BL6_30
BL6_35
Max
Avg
Min
La
Ce
Pr
Nd
Sm
Eu
Gd
Tb
Dy
Ho
Er
Tm
Yb
Lu
B
Ce / Ce*
Eu / Eu*
C
Nb (ppm)
Ta (ppm)
D
Y (ppm)
U (ppm)
2.4 - 1.8 Ga
> 2.5 Ga
BL6_34 (3.94 Ga)
BL6_30 (2.77 Ga)
BL6_35 (2.71 Ga)

Figure 17. Zircon (A) chondrite-normalized REE plot, (B) Ce/Ce* vs. Eu/Eu*, (C) Nb vs. Ta, and (D) Y vs. U for the Lower St. Peter sample. Chondrite values are from McDonough and Sun (1995). Fields for discrimination diagrams (B-D) based on distribution behavior in zircon according to the origin of their protolith are: 1) carbonatites; 2) kimberlites; 3) syenites; 4) mafic rocks; syenite pegmatites; 6) nepheline syenites and 7) granitoids [modified from Belousova et al. (2002) and Shchepetilnikova et al. (2015)].

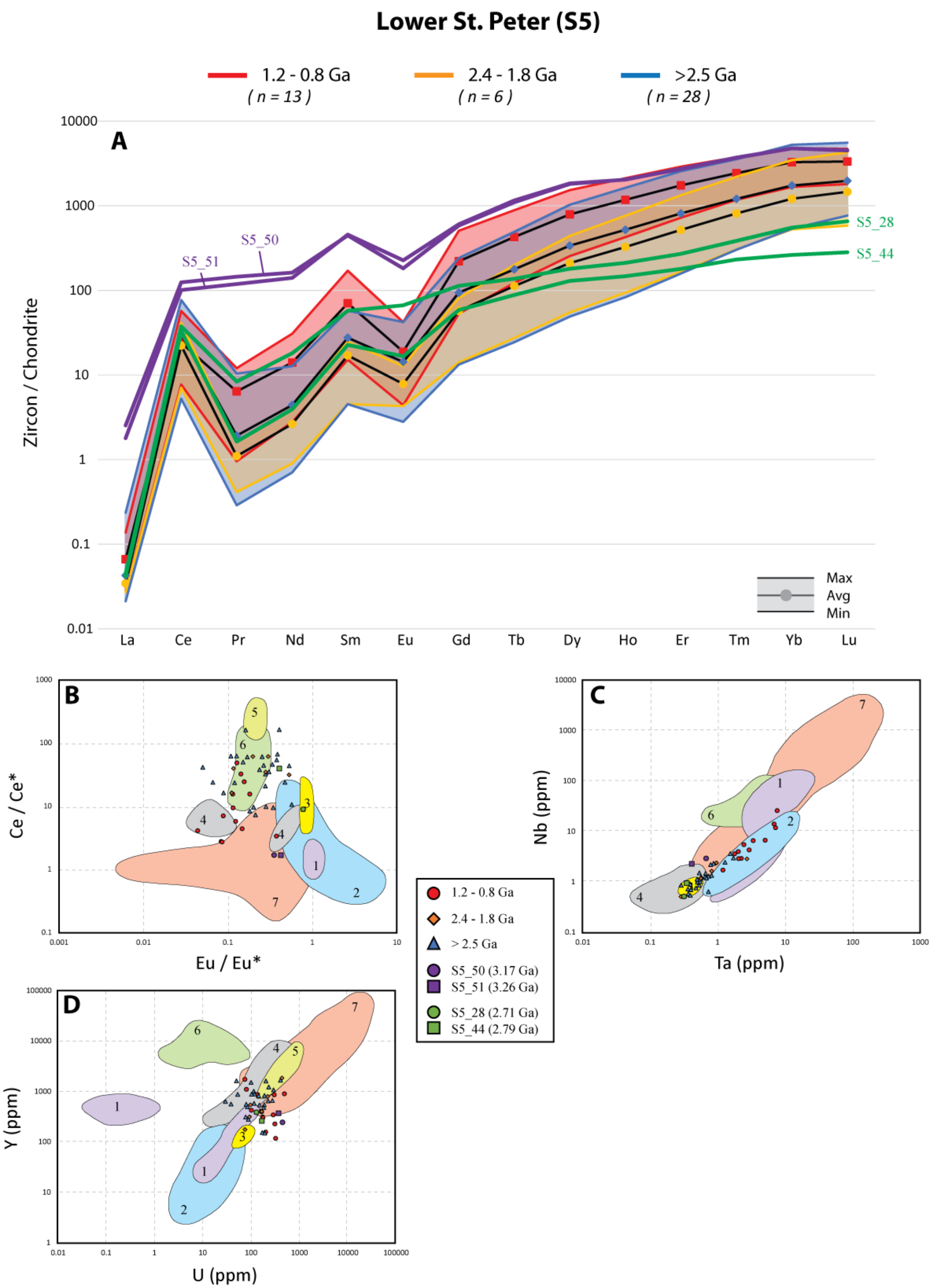

Lower St. Peter (S5)
1.2 - 0.8 Ga
(n = 13)
2.4 - 1.8 Ga
(n = 6)
>2.5 Ga
(n = 28)
A
Zircon / Chondrite
S5_50
S5_51
S5_28
S5_44
Max
Avg
Min
La Ce Pr Nd Sm Eu Gd Tb Dy Ho Er Tm Yb Lu
B
Ce / Ce*
Eu / Eu*
C
Nb (ppm)
Ta (ppm)
D
Y (ppm)
U (ppm)
1.2 - 0.8 Ga
2.4 - 1.8 Ga
> 2.5 Ga
S5_50 (3.17 Ga)
S5_51 (3.26 Ga)
S5_28 (2.71 Ga)
S5_44 (2.79 Ga)

Figure 18. Zircon (A) chondrite-normalized REE plot, (B) Ce/Ce* vs. Eu/Eu*, (C) Nb vs. Ta, and (D) Y vs. U for the Upper St. Peter sample. Chondrite values are from McDonough and Sun (1995). Fields for discrimination diagrams (B-D) based on distribution behavior in zircon according to the origin of their protolith are: 1) carbonatites; 2) kimberlites; 3) syenites; 4) mafic rocks; syenite pegmatites; 6) nepheline syenites and 7) granitoids [modified from Belousova et al. (2002) and Shchepetilnikova et al. (2015)].

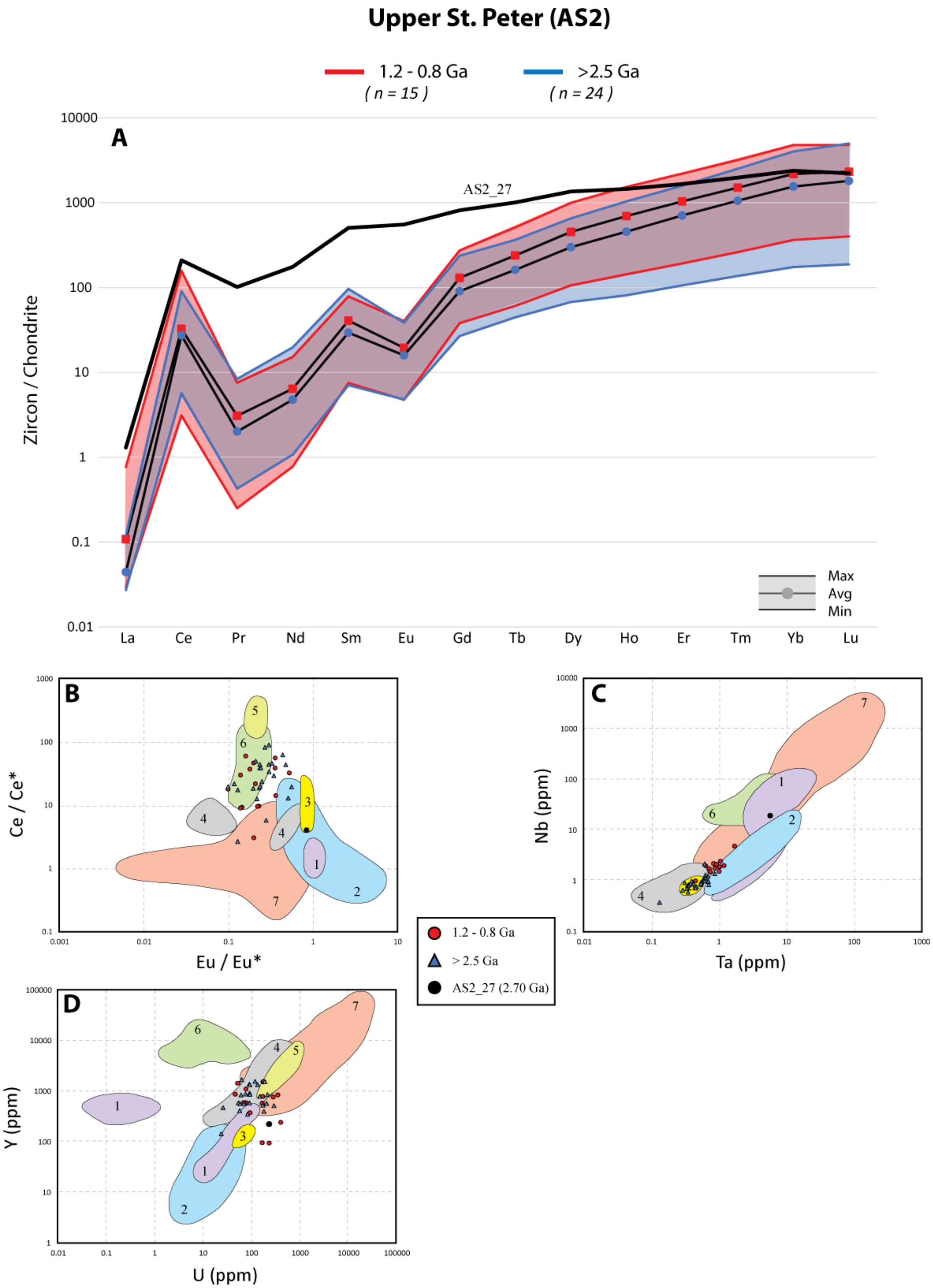
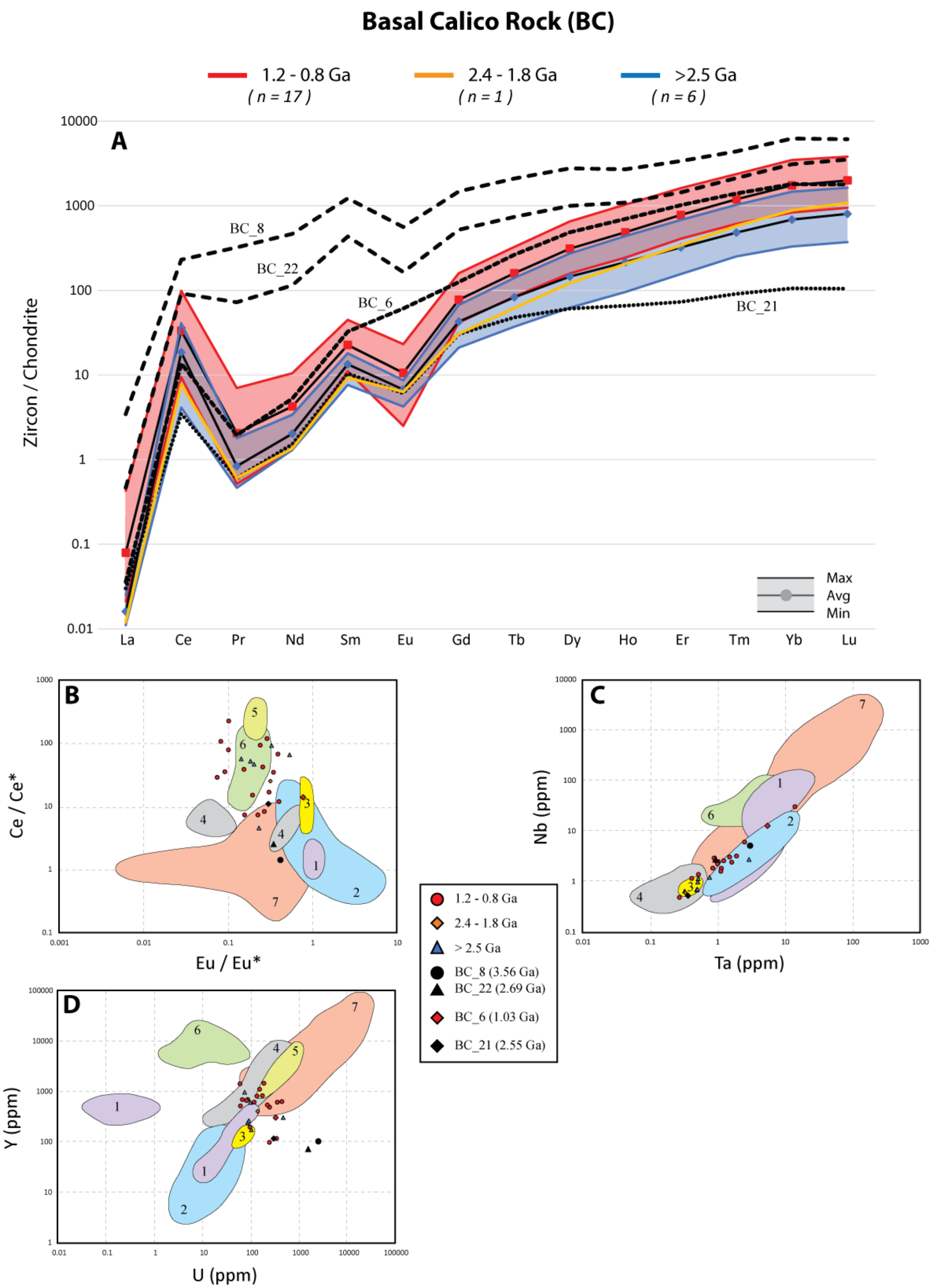
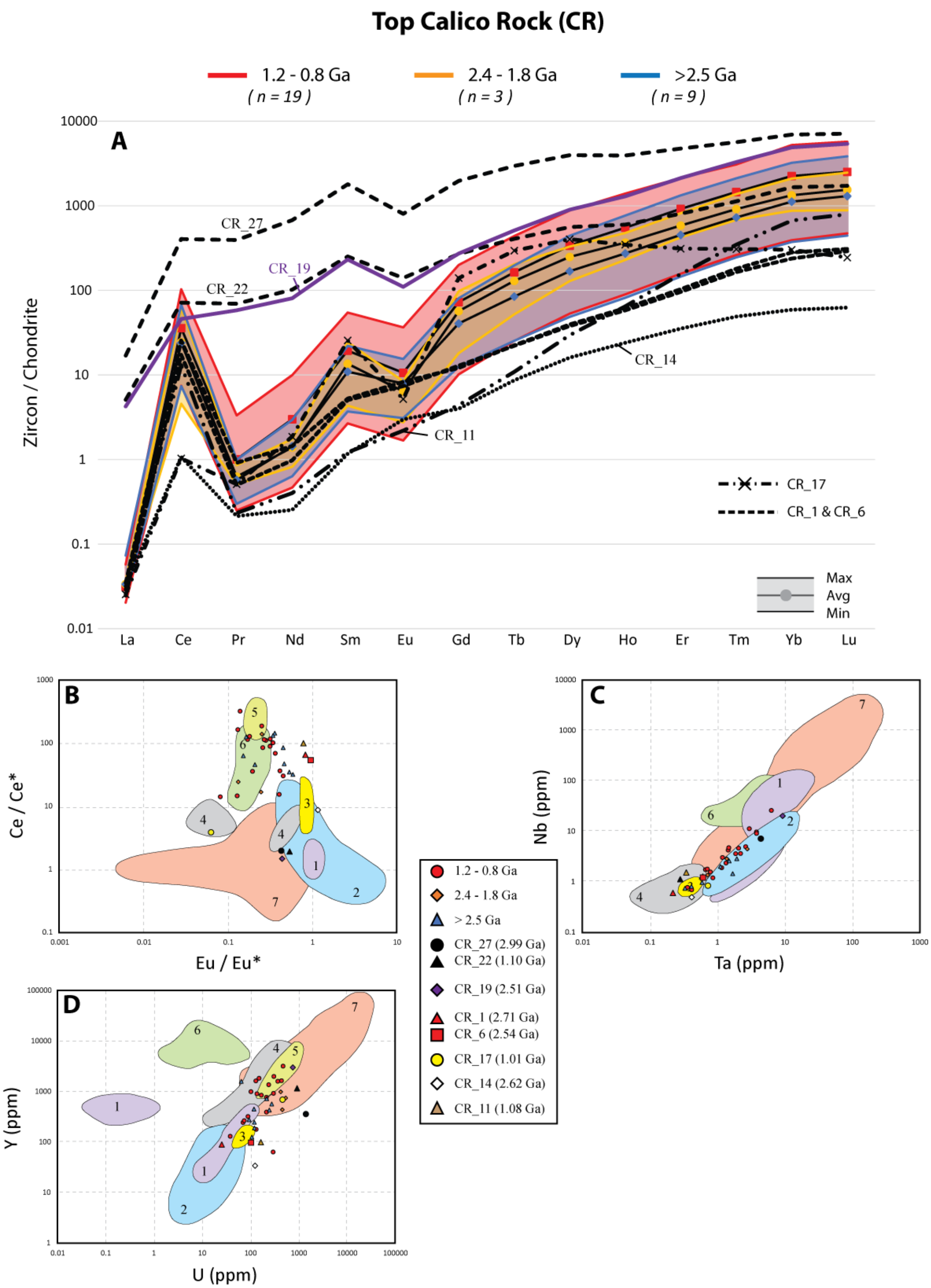

Upper St. Peter (AS2)
1.2 - 0.8 Ga
(n = 15)
>2.5 Ga
(n = 24)
A
AS2_27
Zircon / Chondrite
Max
Avg
Min
La
Ce
Pr
Nd
Sm
Eu
Gd
Tb
Dy
Ho
Er
Tm
Yb
Lu
B
Ce / Ce*
Eu / Eu*
C
Nb (ppm)
Ta (ppm)
1.2 - 0.8 Ga
> 2.5 Ga
AS2_27 (2.70 Ga)
D
Y (ppm)
U (ppm)

Figure 19. Zircon (A) chondrite-normalized REE plot, (B) Ce/Ce* vs. Eu/Eu*, (C) Nb vs. Ta, and (D) Y vs. U for the Basal Calico Rock sample. Chondrite values are from McDonough and Sun (1995). Fields for discrimination diagrams (B-D) based on distribution behavior in zircon according to the origin of their protolith are: 1) carbonatites; 2) kimberlites; 3) syenites; 4) mafic rocks; syenite pegmatites; 6) nepheline syenites and 7) granitoids [modified from Belousova et al. (2002) and Shchepetilnikova et al. (2015)].



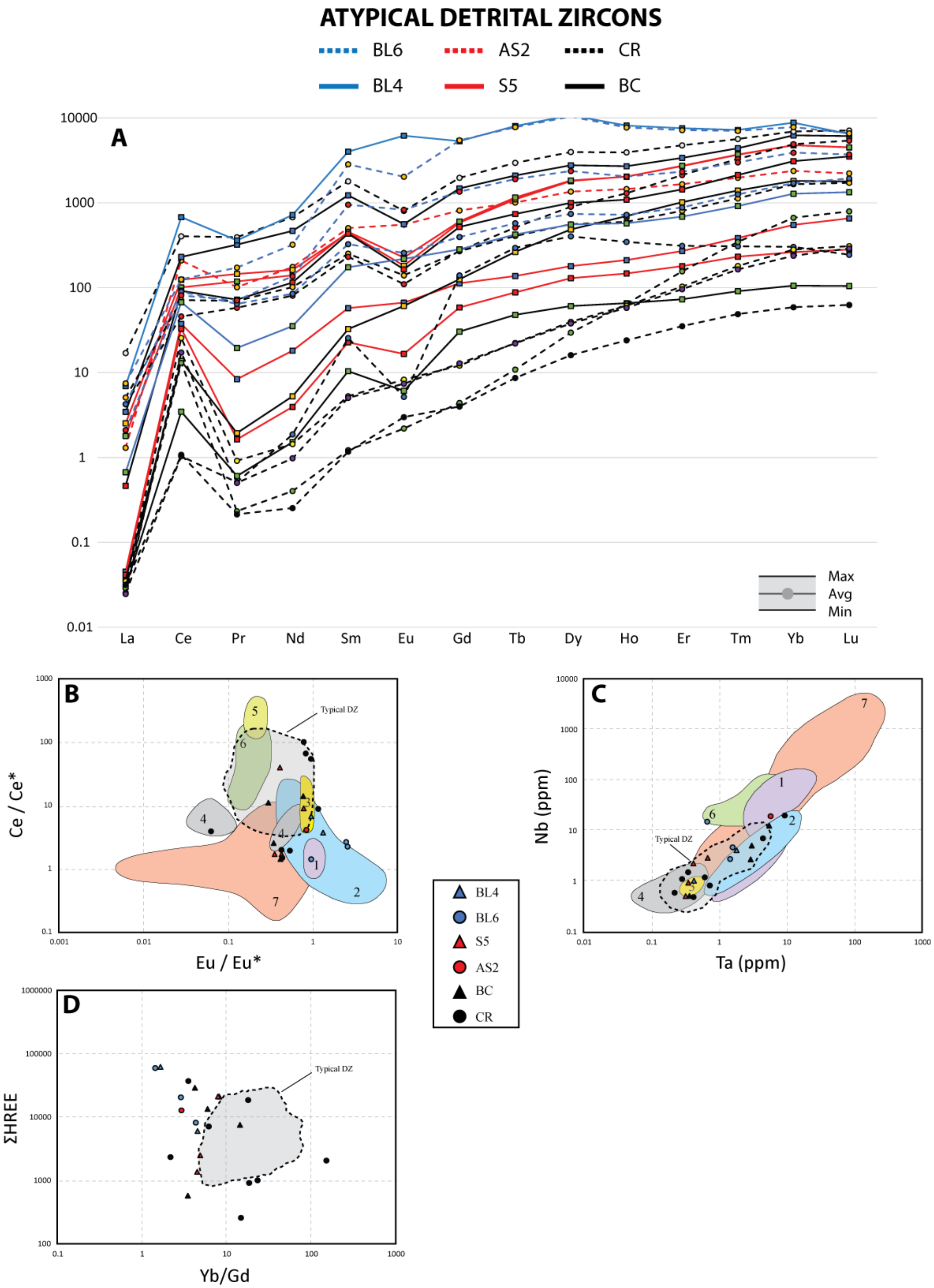
Basal Calico Rock (BC)
1.2 - 0.8 Ga (n = 17)
2.4 - 1.8 Ga (n = 1)
>2.5 Ga (n = 6)
A
Zircon / Chondrite
BC_8
BC_22
BC_6
BC_21
Max
Avg
Min
La Ce Pr Nd Sm Eu Gd Tb Dy Ho Er Tm Yb Lu
B
Ce / Ce*
Eu / Eu*
C
Nb (ppm)
Ta (ppm)
D
Y (ppm)
U (ppm)
1.2 - 0.8 Ga
2.4 - 1.8 Ga
> 2.5 Ga
BC_8 (3.56 Ga)
BC_22 (2.69 Ga)
BC_6 (1.03 Ga)
BC_21 (2.55 Ga)

Figure 20. Zircon (A) chondrite-normalized REE plot, (B) Ce/Ce* vs. Eu/Eu*, (C) Nb vs. Ta, and (D) Y vs. U for the Top Calico Rock sample. Chondrite values are from McDonough and Sun (1995). Fields for discrimination diagrams (B-D) based on distribution behavior in zircon according to the origin of their protolith are: 1) carbonatites; 2) kimberlites; 3) syenites; 4) mafic rocks; syenite pegmatites; 6) nepheline syenites and 7) granitoids [modified from Belousova et al. (2002) and Shchepetilnikova et al. (2015)].



Top Calico Rock (CR)
1.2 - 0.8 Ga (n = 19)
2.4 - 1.8 Ga (n = 3)
>2.5 Ga (n = 9)
A
Zircon / Chondrite
CR_27
CR_19
CR_22
CR_14
CR_11
CR_17
CR_1 & CR_6
Max
Avg
Min
La Ce Pr Nd Sm Eu Gd Tb Dy Ho Er Tm Yb Lu
B
Ce / Ce*
Eu / Eu*
C
Nb (ppm)
Ta (ppm)
D
Y (ppm)
U (ppm)
1.2 - 0.8 Ga
2.4 - 1.8 Ga
> 2.5 Ga
CR_27 (2.99 Ga)
CR_22 (1.10 Ga)
CR_19 (2.51 Ga)
CR_1 (2.71 Ga)
CR_6 (2.54 Ga)
CR_17 (1.01 Ga)
CR_14 (2.62 Ga)
CR_11 (1.08 Ga)

Figure 21. Zircon (A) chondrite-normalized REE plot, (B) Ce/Ce* vs. Eu/Eu*, (C) Nb vs. Ta, and (D) Y vs. U for atypical detrital zircons. Chondrite values are from McDonough and Sun (1995). Fields for discrimination diagrams (B-D) based on distribution behavior in zircon according to the origin of their protolith are: 1) carbonatites; 2) kimberlites; 3) syenites; 4) mafic rocks; syenite pegmatites; 6) nepheline syenites and 7) granitoids [modified from Belousova et al. (2002) and Shchepetilnikova et al. (2015)].


ATYPICAL DETRITAL ZIRCONS
BL6
AS2
CR
BL4
S5
BC
A
Max
Avg
Min
La
Ce
Pr
Nd
Sm
Eu
Gd
Tb
Dy
Ho
Er
Tm
Yb
Lu
B
Typical DZ
Ce / Ce*
Eu / Eu*
C
Typical DZ
Nb (ppm)
Ta (ppm)
BL4
BL6
S5
AS2
BC
CR
D
Typical DZ
ΣHREE
Yb/Gd

APPENDIX B

TABLES

	Belousova et al. (2002)	Wiedenbeck et al. (2004)	Kylander-Clark et al. (2013)	This Study
Standard	*91500*	*91500*	*91500*	*91500*
La	<0.08 ± 0.05	0.006	0.011	0.006
Ce	2.5 ± 0.5	2.56	2.551	2.595
Pr	<0.05 ± 0.05	0.024	0.011	0.021
Nd	<0.35 ± 0.07	0.24	0.225	0.232
Sm	0.41 ± 0.2	0.50	0.405	0.488
Eu	0.37 ± 0.17	0.24	0.228	0.237
Gd	2.1 ± 0.35	2.21	2.284	2.218
Tb	-	0.86	0.863	0.857
Dy	12 ± 2.1	11.8	11.36	12.174
Ho	4.9 ± 0.7	4.84	4.807	4.849
Er	26 ± 3.6	24.6	25.61	25.387
Tm	-	6.89	6.275	6.972
Yb	66 ± 7.3	73.9	67.53	75.186
Lu	14 ± 1.9	13.1	13.44	13.273

Table 1. Results for REE of primary zircon standard 91500 compared to previously published values.

APPENDIX C

DATA TABLES

Data Table 1. Zircon trace element values (ppm) for Morberley Mountain Lower (MM1)

*Red text denotes discarded samples

Sample	207/206 Age	Ti49	Y89	Zr91	Nb93	La139	Ce140	Pr141
MM1_1	1035.1	4.66	108.4	488953	9.08	0.02	31.84	0.61
MM1_2	1042.3	50.88	701.4	187133	11.23	0.10	51.49	0.43
MM1_3	1253.5	341.75	102.0	442996	73.46	7.63	985.25	114.72
MM1_4	1803.3	14.47	931.5	482976	1.03	0.02	5.30	0.36
MM1_5	1806.8	8.23	1195.9	501063	2.21	0.02	19.26	0.36
MM1_6	1821.1	12.07	613.8	516875	3.09	0.12	24.23	0.51
MM1_7	1823.0	34.48	618.1	468693	0.77	0.02	24.69	0.72
MM1_8	1827.4	11.05	604.4	471365	1.90	0.01	17.67	0.10
MM1_9	1828.1	6.91	118.5	523418	2.17	0.01	9.82	0.30
MM1_10	1839.0	23.29	659.6	515536	2.33	0.01	20.65	0.14
MM1_11	1839.4	18.52	754.1	512904	2.04	0.01	12.91	0.11
MM1_12	1840.2	18.22	1071.0	512410	2.80	0.01	16.72	0.16
MM1_13	1842.2	14.76	571.5	501031	2.43	0.06	6.93	0.11
MM1_14	1843.4	14.80	637.9	507201	2.31	0.01	12.06	0.09
MM1_15	1846.1	18.72	948.9	519297	2.44	0.01	21.18	0.16
MM1_16	1847.4	58.37	546.9	201926	3.45	0.35	22.65	1.33
MM1_17	1848.8	5.60	698.3	511288	1.07	0.21	15.53	0.74
MM1_18	1858.3	15.04	644.2	512675	2.03	0.01	18.45	0.18
MM1_19	1862.9	21.33	398.5	537543	2.27	0.01	33.45	0.18
MM1_20	1863.7	12.64	1021.4	464250	3.45	0.03	13.20	0.33
MM1_21	1874.3	11.00	110.4	492436	3.05	0.01	6.30	0.19
MM1_22	1879.8	12.97	530.8	499657	3.31	0.01	12.61	0.10
MM1_23	1882.8	8.15	665.1	479447	1.17	0.01	12.53	0.16
MM1_24	1883.0	17.08	494.3	497873	2.55	0.01	10.53	0.10
MM1_25	1914.3	14.05	866.8	478747	3.44	0.01	13.47	0.12
MM1_26	1800.0	7.93	825.2	473197	4.18	0.02	36.98	0.16
MM1_27	1928.7	25.72	349.6	495809	1.01	0.01	7.03	0.24
MM1_28	1927.5	6.22	381.8	492672	1.42	0.01	26.28	0.13
MM1_29	1928.9	14.79	478.5	492921	2.30	0.01	9.59	0.07
MM1_30	1930.7	14.69	830.9	506749	4.64	0.01	18.33	0.12
MM1_31	1932.5	9.97	687.2	497070	2.36	0.01	18.81	0.08
MM1_32	1941.6	7.81	1304.6	489873	8.15	0.01	5.85	0.03
MM1_33	1949.4	5.41	1207.9	479817	3.09	0.01	11.30	0.11
MM1_34	1949.4	15.52	666.1	487245	1.73	0.01	18.93	0.11
MM1_35	2080.0	6.92	1347.7	495279	1.53	0.02	11.75	0.38
MM1_36	1985.7	15.50	969.4	511819	1.93	0.01	36.04	0.27
MM1_37	2050.6	13.16	714.7	506486	2.05	0.01	16.89	0.06
MM1_38	1938.3	15.67	760.4	494753	1.23	0.01	7.67	0.17
MM1_39	2065.3	34.51	898.7	500928	1.86	0.01	23.12	0.23
MM1_40	1924.6	22.78	404.0	452638	1.56	0.01	50.11	0.24
MM1_41	2068.7	9.56	1478.7	506337	0.99	0.01	9.64	0.17
MM1_42	2076.1	9.85	1027.1	505034	1.05	0.01	3.36	0.13
MM1_43	2077.0	13.25	658.8	515503	2.49	0.01	28.53	0.05
MM1_44	2054.7	15.11	512.4	477331	1.50	0.01	11.27	0.06
MM1_45	1862.2	8.72	462.0	498411	4.24	0.11	25.98	0.19
MM1_46	2535.8	15.01	798.8	491003	1.82	0.01	19.54	0.13
MM1_47	2697.7	7.81	401.2	495137	1.21	0.02	26.20	0.10
MM1_48	2675.4	10.04	1489.6	496557	1.58	0.01	12.93	0.11
MM1_49	2571.6	8.48	207.0	502007	0.75	0.00	5.44	0.03
MM1_50	2778.7	13.74	355.7	500753	0.70	0.01	26.43	0.10
MM1_51	2606.4	8.79	835.5	491202	1.27	0.01	8.23	0.08

Data Table 1. Zircon trace element values (ppm) for Morberley Mountain Lower (MM1) (CONT.)

Sample	Nd146	Sm147	Eu151	Eu153	Gd157	Tb159	Dy163	Ho165
MM1_1	7.73	15.69	1.61	1.44	67.13	24.59	335.18	118.56
MM1_2	4.42	10.85	1.63	1.72	44.86	21.01	335.04	114.01
MM1_3	771.08	955.72	460.56	466.36	3376.1	1070.9	249.82	64.70
MM1_4	4.79	8.76	0.76	0.71	36.51	12.23	151.50	50.91
MM1_5	4.29	7.29	1.31	1.27	28.12	8.72	107.15	36.30
MM1_6	3.44	5.02	1.05	1.05	15.85	5.71	78.60	23.53
MM1_7	7.64	10.51	1.97	1.90	29.00	7.62	67.72	17.41
MM1_8	1.21	1.71	0.19	0.15	9.12	3.47	47.75	17.40
MM1_9	3.70	7.83	0.57	0.50	38.66	13.33	174.57	58.87
MM1_10	1.42	2.57	0.44	0.52	11.68	3.85	52.40	18.38
MM1_11	1.35	2.43	0.30	0.34	12.06	4.38	57.21	21.01
MM1_12	2.17	3.38	0.52	0.49	15.15	5.74	74.67	26.15
MM1_13	0.98	1.75	0.17	0.13	9.41	3.41	46.36	17.42
MM1_14	1.19	2.50	0.22	0.20	11.35	3.98	52.75	18.74
MM1_15	1.64	3.19	0.41	0.44	14.76	4.77	67.42	23.98
MM1_16	7.00	7.48	2.50	2.49	20.63	6.38	76.89	22.55
MM1_17	5.34	5.30	1.06	1.03	18.19	5.28	62.12	20.01
MM1_18	1.71	2.71	0.47	0.45	11.04	3.79	50.45	17.48
MM1_19	1.88	3.06	0.65	0.68	10.74	3.27	38.23	12.17
MM1_20	1.83	3.52	0.60	0.77	15.07	4.85	70.23	24.30
MM1_21	2.23	5.77	0.30	0.26	34.04	12.96	187.18	68.71
MM1_22	1.12	2.24	0.21	0.21	10.48	3.66	47.48	16.24
MM1_23	0.89	2.12	0.36	0.33	11.26	3.92	51.91	19.34
MM1_24	1.22	2.30	0.28	0.28	9.92	3.52	44.33	15.42
MM1_25	1.42	2.80	0.20	0.16	13.46	4.85	68.30	24.50
MM1_26	1.31	2.63	0.29	0.33	12.19	4.45	62.62	22.91
MM1_27	2.53	4.21	0.37	0.39	14.14	3.94	41.23	11.02
MM1_28	1.39	1.93	0.39	0.41	7.53	2.47	30.09	11.15
MM1_29	1.03	1.87	0.19	0.20	8.80	2.98	40.89	14.83
MM1_30	1.79	3.39	0.25	0.26	16.25	5.42	69.73	23.83
MM1_31	1.27	2.98	0.26	0.25	13.82	4.88	60.44	19.39
MM1_32	0.40	1.51	0.13	0.10	12.28	5.98	85.62	32.96
MM1_33	1.54	2.86	0.29	0.28	16.24	5.88	84.52	31.44
MM1_34	1.22	2.61	0.40	0.39	11.28	3.96	54.05	19.38
MM1_35	4.00	5.47	0.45	0.44	20.42	7.17	94.16	34.55
MM1_36	3.17	5.29	1.30	1.18	19.59	6.23	77.57	26.59
MM1_37	0.82	1.96	0.23	0.21	9.19	3.60	51.05	20.10
MM1_38	2.59	5.86	0.30	0.29	22.41	6.83	73.11	21.48
MM1_39	2.91	5.17	1.46	1.42	19.65	6.24	78.49	25.59
MM1_40	2.75	3.63	0.99	0.86	10.83	3.38	39.33	12.63
MM1_41	2.56	5.58	0.59	0.53	28.02	9.78	130.02	45.69
MM1_42	2.13	4.85	0.24	0.19	23.60	8.33	115.33	40.97
MM1_43	0.81	1.80	0.46	0.38	8.18	3.30	44.93	18.53
MM1_44	0.86	1.79	0.22	0.20	7.94	3.08	40.07	15.43
MM1_45	1.24	2.24	0.30	0.32	8.83	3.03	37.96	13.46
MM1_46	1.64	3.83	0.28	0.29	16.33	5.38	65.28	22.25
MM1_47	0.92	1.71	0.39	0.38	7.79	2.73	33.43	12.13
MM1_48	1.39	3.20	0.25	0.21	16.13	6.75	94.96	37.04
MM1_49	0.30	0.73	0.21	0.16	3.40	1.32	17.57	6.65
MM1_50	1.24	2.54	0.72	0.79	9.91	2.81	32.15	11.46
MM1_51	1.04	2.72	0.37	0.33	13.49	4.98	65.54	23.75

Data Table 1. Zircon trace element values (ppm) for Morberley Mountain Lower (MM1) (CONT.)

Sample	Er166	Tm169	Yb172	Lu175	Hf179	Ta181	Th232	U238
MM1_1	508.80	106.95	1030.3	145.9	6716	3.61	111.1	178.4
MM1_2	518.33	111.89	700.4	123.7	2333	1.59	122.6	61.9
MM1_3	212.44	47.46	271.9	110.6	16205	15.03	15457	9683.6
MM1_4	209.92	44.29	401.4	64.0	7791	0.45	71.0	119.1
MM1_5	149.61	31.66	292.0	46.1	9895	0.66	106.0	74.3
MM1_6	98.38	22.61	202.4	29.7	11460	1.27	196.2	178.5
MM1_7	61.83	12.31	114.0	14.2	8497	0.36	86.2	52.0
MM1_8	81.35	19.24	189.3	32.4	11062	1.15	72.9	131.2
MM1_9	247.69	53.58	496.4	75.7	10205	0.81	108.1	158.3
MM1_10	83.84	19.58	185.4	32.3	10731	0.98	58.1	60.8
MM1_11	95.50	22.33	206.4	37.0	10931	0.97	56.5	84.2
MM1_12	118.01	27.58	278.9	44.1	10921	1.32	58.4	112.6
MM1_13	76.94	17.39	161.8	28.6	9726	0.94	47.8	104.0
MM1_14	83.36	19.09	172.8	30.5	10704	0.98	52.3	85.3
MM1_15	110.14	24.93	244.3	40.5	11031	1.11	78.7	107.1
MM1_16	91.18	18.60	170.1	34.4	4045	1.29	168.3	103.9
MM1_17	83.88	17.86	163.0	29.0	11294	0.63	48.3	75.9
MM1_18	80.75	18.78	179.5	30.5	10362	0.82	49.6	52.3
MM1_19	50.97	11.24	102.3	17.2	10245	0.84	73.6	86.3
MM1_20	112.69	26.86	217.0	37.1	8787	1.34	72.3	152.1
MM1_21	328.65	75.07	764.3	125.4	11687	1.27	169.7	438.1
MM1_22	71.35	15.51	141.0	24.5	10811	1.39	75.4	99.0
MM1_23	90.04	20.36	198.2	34.9	11296	0.61	107.8	186.4
MM1_24	66.46	14.60	132.5	23.0	10201	1.10	62.6	81.4
MM1_25	111.24	24.89	236.8	40.3	11440	1.81	76.9	87.1
MM1_26	107.85	25.60	261.6	45.0	11301	1.84	187.9	234.4
MM1_27	39.91	7.34	57.3	7.7	11704	0.34	167.5	84.0
MM1_28	50.35	12.14	121.7	20.5	9779	0.63	87.4	107.4
MM1_29	67.75	15.56	159.4	26.0	11439	1.15	47.6	55.3
MM1_30	100.68	21.43	192.1	32.4	11240	1.95	137.3	158.3
MM1_31	82.92	18.12	169.9	26.9	12658	0.95	168.4	196.7
MM1_32	157.35	35.41	341.6	53.5	13061	4.35	28.0	281.3
MM1_33	141.38	31.90	307.6	51.4	10284	1.31	44.6	90.6
MM1_34	87.86	20.13	193.2	33.4	10517	0.70	96.6	103.7
MM1_35	156.07	35.51	339.8	56.7	9335	0.45	76.6	76.7
MM1_36	111.69	24.87	228.2	39.7	9738	0.69	95.6	54.0
MM1_37	96.02	23.64	239.2	42.0	12097	0.85	59.5	95.2
MM1_38	82.40	16.95	150.0	24.0	11791	0.51	159.8	161.9
MM1_39	105.99	23.38	219.6	36.7	10058	0.76	46.7	33.5
MM1_40	52.59	12.90	131.3	18.8	8793	0.66	99.4	87.9
MM1_41	199.54	43.11	386.1	64.3	10940	0.40	82.2	77.2
MM1_42	180.10	39.15	382.9	61.3	10475	0.49	45.1	77.4
MM1_43	91.58	23.95	258.8	44.0	11431	1.13	70.1	117.1
MM1_44	72.23	17.55	172.4	31.0	10289	0.57	32.5	41.1
MM1_45	60.22	14.48	142.3	23.9	11440	1.68	187.7	349.5
MM1_46	91.83	19.64	179.4	28.3	10480	0.72	207.1	116.6
MM1_47	53.37	12.40	116.0	20.7	10951	0.50	125.4	91.8
MM1_48	168.64	38.99	362.1	59.2	11061	0.62	46.7	80.9
MM1_49	31.33	7.64	73.7	13.6	10079	0.32	32.8	62.4
MM1_50	48.77	11.36	110.8	19.8	9965	0.31	72.3	81.2
MM1_51	101.99	22.76	210.2	35.6	9488	0.55	87.2	194.1

Data Table 2. Zircon trace element values (ppm) for Morberley Mountain Upper (MM3)

*Red text denotes discarded samples

Sample	207/206 Age	Ti49	Y89	Zr91	Nb93	La139	Ce140	Pr141
MM3_1	1060.7	10.12	124.7	477768	4.69	0.08	14.73	0.85
MM3_2	1088.1	11.03	468.2	477425	4.56	0.01	11.30	0.10
MM3_3	1032.8	5.46	138.0	461052	32.22	0.01	44.79	0.28
MM3_4	1812.3	7.80	682.2	461798	1.38	0.01	12.73	0.12
MM3_5	1826.7	9.20	785.1	459657	3.30	0.01	20.96	0.06
MM3_6	1827.9	20.50	663.2	463024	2.76	0.01	23.01	0.08
MM3_7	1828.7	17.23	898.0	461109	3.61	0.01	27.52	0.10
MM3_8	1830.7	11.18	739.1	450006	6.41	0.04	24.26	0.11
MM3_9	1834.8	27.05	741.9	464703	1.82	0.01	15.04	0.09
MM3_10	1836.6	16.77	614.6	460163	2.26	0.01	17.46	0.06
MM3_11	1844.1	27.64	703.7	452891	1.88	0.01	18.84	0.13
MM3_12	1853.1	4.13	1849.8	462870	3.05	0.02	16.41	0.30
MM3_13	1858.9	17.66	457.2	463300	1.93	0.01	25.92	0.06
MM3_14	1873.0	9.19	828.4	459054	2.11	0.01	8.95	0.09
MM3_15	1876.1	4.16	1288.6	457729	2.09	0.01	19.44	0.32
MM3_16	1884.7	4.29	1602.5	450259	3.16	0.02	21.05	0.49
MM3_17	1900.1	23.01	659.4	365331	2.12	0.13	8.60	0.12
MM3_18	1908.9	14.44	906.2	459446	8.28	0.01	15.10	0.10
MM3_19	1909.0	27.69	574.5	457550	1.35	0.01	14.08	0.10
MM3_20	1918.6	23.75	933.6	460174	2.09	0.01	9.24	0.14
MM3_21	1920.6	12.36	383.4	454960	1.34	0.01	9.70	0.05
MM3_22	1921.4	9.81	774.5	439673	1.42	0.03	22.62	0.58
MM3_23	1921.5	23.82	530.4	461609	1.16	0.01	7.06	0.14
MM3_24	1923.9	13.87	719.8	452988	1.82	0.01	73.48	0.26
MM3_25	1924.4	16.62	485.5	461964	1.81	0.01	17.71	0.09
MM3_26	1924.5	27.31	513.6	456496	1.53	0.01	6.51	0.17
MM3_27	1932.8	6.00	1925.7	448358	2.32	0.01	7.36	0.09
MM3_28	1933.7	23.63	745.9	451503	1.68	0.01	21.77	0.21
MM3_29	1943.2	14.30	552.3	450260	1.21	0.01	4.02	0.10
MM3_30	1943.2	17.71	467.9	460846	1.56	0.01	15.61	0.08
MM3_31	1949.9	33.12	449.6	448812	1.29	0.01	11.59	0.15
MM3_32	1952.8	28.94	722.8	464029	1.07	0.01	8.37	0.16
MM3_33	1956.6	13.50	1133.0	454746	2.29	0.01	14.73	0.08
MM3_34	2025.5	7.34	770.6	446165	1.91	0.01	8.21	0.09
MM3_35	2052.5	10.75	586.4	447445	1.22	0.01	5.92	0.03
MM3_36	2062.9	20.37	590.4	465590	1.28	0.01	15.46	0.07
MM3_37	2075.9	11.23	2181.1	460692	9.12	0.01	45.64	0.09
MM3_38	2076.4	23.03	1647.1	466716	3.77	0.01	47.20	0.18
MM3_39	2085.1	26.19	411.0	454412	1.02	0.05	11.69	1.11
MM3_40	2088.5	23.25	1329.1	453152	1.06	0.02	20.33	0.86
MM3_41	2091.4	5.92	670.6	447912	6.10	0.01	17.29	0.05
MM3_42	2216.9	24.11	444.0	454365	0.85	0.01	7.18	0.12
MM3_43	2262.8	2.56	324.8	458024	1.15	0.01	18.87	0.07
MM3_44	2495.8	3.49	439.9	457510	1.72	0.01	17.14	0.08
MM3_45	2619.0	1.16	347.2	452153	0.70	0.01	8.82	0.07
MM3_46	2664.5	4.76	300.1	455989	0.80	0.01	12.26	0.04
MM3_47	2704.4	1.02	1459.9	461109	0.81	0.01	6.96	0.08
MM3_48	2716.9	2.23	255.2	445731	0.70	31.19	244.64	87.04
MM3_49	2729.8	1.61	733.5	452351	0.84	0.01	10.98	0.07
MM3_50	2907.5	1.90	701.3	451736	2.86	0.01	54.72	0.11
MM3_51	4035.6	5775.0	1405.9	57479	14502	302.39	3181.3	181.79

Data Table 2. Zircon trace element values (ppm) for Morberley Mountain Upper (MM3) (CONT.)

Sample	Nd146	Sm147	Eu151	Eu153	Gd157	Tb159	Dy163	Ho165
MM3_1	8.60	11.52	1.07	1.12	54.51	19.77	257.49	93.42
MM3_2	1.36	2.73	0.19	0.16	10.98	3.56	44.10	15.23
MM3_3	3.95	9.21	1.56	1.66	43.8	20.2	303.17	115.28
MM3_4	1.33	2.16	0.27	0.30	9.90	3.83	49.52	18.12
MM3_5	0.89	1.89	0.18	0.18	8.40	3.60	48.98	19.28
MM3_6	0.97	2.15	0.33	0.37	10.11	3.86	49.22	17.95
MM3_7	1.38	2.80	0.34	0.32	12.78	4.81	61.91	22.65
MM3_8	1.28	2.40	0.36	0.32	10.61	4.10	53.59	19.69
MM3_9	1.15	2.67	0.39	0.43	10.97	4.35	55.38	19.47
MM3_10	0.91	2.02	0.24	0.25	9.08	3.50	46.52	17.03
MM3_11	1.60	3.23	0.73	0.76	12.89	4.75	56.91	19.50
MM3_12	3.29	5.71	0.46	0.51	22.69	8.27	106.04	37.84
MM3_13	0.92	1.78	0.40	0.39	7.42	3.03	36.20	12.94
MM3_14	1.30	3.23	0.21	0.24	13.36	5.00	59.64	20.43
MM3_15	3.57	7.06	0.85	0.91	24.47	8.15	96.41	30.01
MM3_16	4.73	8.36	1.83	1.77	34.14	11.86	151.29	50.84
MM3_17	1.12	1.98	0.19	0.27	9.69	3.66	49.14	17.23
MM3_18	1.14	2.86	0.17	0.14	12.91	4.97	69.65	23.80
MM3_19	1.18	2.70	0.59	0.52	10.03	3.55	47.37	16.46
MM3_20	1.35	3.07	0.33	0.32	14.25	5.27	70.37	24.13
MM3_21	0.58	1.71	0.19	0.17	7.22	2.82	35.94	12.10
MM3_22	5.07	7.27	1.10	1.01	21.71	6.54	71.15	21.02
MM3_23	1.53	3.32	0.20	0.16	12.49	3.98	47.33	15.25
MM3_24	2.72	5.36	1.00	1.02	17.96	5.26	61.48	19.49
MM3_25	0.91	1.91	0.31	0.27	8.09	2.93	39.39	14.05
MM3_26	1.71	3.74	0.37	0.31	13.62	4.42	51.91	15.02
MM3_27	1.11	3.92	0.21	0.21	20.20	8.30	113.59	40.65
MM3_28	1.99	4.28	0.48	0.45	16.60	5.44	65.61	20.72
MM3_29	1.30	3.92	0.19	0.21	16.70	5.35	54.61	15.83
MM3_30	0.92	1.99	0.29	0.32	8.34	3.02	38.55	13.94
MM3_31	1.66	3.46	0.47	0.52	12.33	4.01	44.96	14.19
MM3_32	1.82	3.90	0.25	0.25	15.60	5.09	59.95	19.84
MM3_33	0.92	2.39	0.22	0.25	12.49	5.03	71.48	27.35
MM3_34	0.98	2.28	0.20	0.16	11.41	4.29	56.46	20.90
MM3_35	0.24	0.59	0.20	0.19	4.56	2.21	36.21	15.68
MM3_36	0.94	1.92	0.26	0.25	8.86	3.53	47.66	17.59
MM3_37	1.15	3.00	0.20	0.19	17.82	7.57	108.35	43.53
MM3_38	2.26	5.36	0.47	0.51	27.82	10.42	141.80	54.15
MM3_39	10.42	13.78	1.12	1.26	50.69	16.25	192.88	63.45
MM3_40	8.81	11.92	0.88	0.96	43.98	14.21	173.62	59.71
MM3_41	0.57	1.39	0.07	0.07	7.31	3.25	49.98	19.61
MM3_42	1.05	1.64	0.68	0.66	6.07	2.04	28.23	11.78
MM3_43	0.65	1.10	0.21	0.21	5.06	1.75	24.56	9.26
MM3_44	0.84	1.56	0.33	0.34	7.76	2.68	36.33	13.21
MM3_45	0.53	1.13	0.26	0.25	6.10	2.10	28.09	10.50
MM3_46	0.50	0.99	0.30	0.32	5.33	1.84	24.62	9.07
MM3_47	1.30	3.66	0.71	0.78	22.47	7.86	98.42	34.00
MM3_48	224.81	38.55	5.27	5.65	26.54	3.24	26.48	7.74
MM3_49	0.74	2.12	0.81	0.78	11.56	4.07	52.09	19.18
MM3_50	1.13	2.18	0.49	0.50	9.72	3.53	47.09	18.18
MM3_51	501.80	95.23	34.16	34.72	161.67	33.30	263.60	61.73

Data Table 2. Zircon trace element values (ppm) for Morberley Mountain Upper (MM3) (CONT.)

Sample	Er166	Tm169	Yb172	Lu175	Hf179	Ta181	Th232	U238
MM3_1	417.19	86.22	867.2	127.8	8362	2.95	188.1	228.3
MM3_2	66.47	15.77	158.7	28.8	7253	1.89	39.2	49.3
MM3_3	558.47	119.42	1226.2	138.7	6692	10.59	257	494.2
MM3_4	83.11	19.35	192.0	31.1	9842	0.71	46.1	97.9
MM3_5	96.62	25.01	267.9	44.8	11479	1.64	184.5	344.9
MM3_6	84.55	20.24	207.7	34.9	10337	1.18	91.7	111.3
MM3_7	103.33	24.43	246.6	39.4	10458	1.50	110.2	139.5
MM3_8	92.31	22.79	244.3	41.3	10439	2.62	145.7	205.0
MM3_9	87.21	19.85	200.5	31.9	9146	0.75	53.1	71.6
MM3_10	78.56	18.50	184.3	30.6	10114	1.05	71.3	120.7
MM3_11	83.48	18.84	188.1	31.0	9523	0.72	36.3	37.0
MM3_12	167.45	36.03	355.0	56.2	8535	0.82	132.5	162.4
MM3_13	60.64	14.85	158.5	25.4	10137	0.85	59.2	81.6
MM3_14	89.41	20.30	195.8	31.7	10300	0.82	244.8	426.1
MM3_15	118.39	25.18	233.8	35.3	8521	0.76	119.4	134.3
MM3_16	212.29	44.67	425.8	67.4	8421	1.18	184.9	116.9
MM3_17	76.09	16.88	165.5	25.4	7351	0.93	44.6	45.8
MM3_18	101.86	22.71	214.6	33.9	10541	3.26	89.2	143.3
MM3_19	71.97	16.41	158.9	26.7	8862	0.50	48.8	49.7
MM3_20	102.45	22.54	216.0	33.9	9643	0.88	43.9	40.0
MM3_21	50.02	10.86	102.3	16.1	10898	0.49	138.4	237.7
MM3_22	80.63	17.04	147.8	22.8	8724	0.69	131.8	93.8
MM3_23	62.57	13.63	126.3	20.4	10200	0.42	134.6	105.0
MM3_24	81.51	17.82	170.7	28.0	9552	0.48	166.2	100.2
MM3_25	63.83	15.34	150.8	25.2	10417	0.82	71.0	100.5
MM3_26	58.44	12.31	105.4	16.1	10998	0.78	56.7	77.8
MM3_27	186.56	43.96	444.7	72.5	12314	1.05	120.4	332.1
MM3_28	83.60	18.47	164.7	25.5	10921	0.83	158.8	152.4
MM3_29	59.50	11.79	104.5	15.6	10677	0.61	193.1	400.7
MM3_30	62.23	14.69	148.4	24.8	10032	0.73	61.2	90.3
MM3_31	56.31	12.08	111.2	18.0	9748	0.62	48.6	54.8
MM3_32	83.27	18.40	175.2	29.1	10227	0.41	92.6	104.9
MM3_33	129.32	30.94	323.3	53.2	10777	1.20	50.4	105.0
MM3_34	93.19	21.21	206.8	34.5	9746	0.89	74.2	119.5
MM3_35	82.51	21.88	247.0	45.5	11210	0.64	159.1	85.5
MM3_36	75.41	16.91	163.6	27.1	9328	0.62	38.5	68.5
MM3_37	208.99	51.16	547.3	87.8	12338	3.51	240.4	433.8
MM3_38	243.35	56.40	594.8	95.1	10403	1.34	125.2	112.0
MM3_39	259.10	53.05	527.8	74.8	8796	0.49	147.1	79.4
MM3_40	241.98	50.34	483.4	71.3	9206	0.50	148.1	108.2
MM3_41	87.99	24.05	270.4	40.5	12154	3.11	175.7	317.1
MM3_42	61.36	17.65	208.7	42.6	7991	0.43	71.9	160.2
MM3_43	44.58	11.28	121.1	21.7	10902	0.66	30.4	35.1
MM3_44	58.42	14.19	136.0	24.3	9917	0.93	54.5	102.8
MM3_45	47.25	10.96	108.0	19.2	8654	0.30	41.8	48.7
MM3_46	42.63	10.53	110.6	19.6	9421	0.34	48.1	109.6
MM3_47	139.43	30.15	283.2	45.3	8978	0.42	58.1	96.9
MM3_48	32.21	7.67	75.2	13.5	9009	0.34	78.7	93.1
MM3_49	86.45	20.99	214.1	36.3	8875	0.42	56.5	166.7
MM3_50	86.40	22.14	241.8	42.0	8650	0.86	112.9	156.2
MM3_51	205.35	34.48	226.9	49.4	1630	385.22	2760.2	888.6

Data Table 3. Zircon trace element values (ppm) for Bear Lake Lower (BL4)

*Red text denotes discarded samples

Sample	207/206 Age	Ti49	Y89	Zr91	Nb93	La139	Ce140	Pr141
BL4_1	1844.4	13.37	444.1	450461	0.82	0.00	13.89	0.06
BL4_2	2816.4	13.38	338.4	458882	0.82	0.01	12.21	0.07
BL4_3	2978.9	8.99	392.8	474790	0.54	0.01	5.49	0.06
BL4_4	2711.7	6.73	142.7	472543	0.72	0.02	4.82	0.07
BL4_5	2709.3	13.56	412.7	465832	0.70	0.01	21.49	0.09
BL4_6	2678.5	6.92	882.9	468975	1.31	0.02	29.54	0.19
BL4_7	2709.7	13.20	274.4	469199	0.60	0.01	18.09	0.06
BL4_8	2703.8	15.50	522.1	449433	0.97	0.01	34.48	0.16
BL4_9	1828.7	9.68	462.8	453058	3.24	0.01	23.49	0.04
BL4_10	2717.3	19.31	239.4	462485	1.02	0.03	19.39	0.20
BL4_11	2705.3	18.49	163.8	465561	0.53	0.02	15.34	0.08
BL4_12	1855.5	19.09	438.3	478800	0.93	0.01	13.58	0.08
BL4_13	2707.9	26.90	858.9	474718	1.24	0.03	15.69	0.42
BL4_14	2700.8	19.43	690.3	479789	1.27	0.06	22.73	0.34
BL4_15	2696.3	12.53	305.5	477518	1.03	0.16	40.71	1.74
BL4_16	2094.2	11.35	328.1	475804	1.49	0.01	9.67	0.07
BL4_17	3095.5	15.98	69.2	451047	0.83	4.65	79.16	12.35
BL4_18	1895.6	7.78	237.6	479285	0.64	0.01	11.32	0.04
BL4_19	1917.7	11.67	848.6	460633	2.75	0.01	12.46	0.11
BL4_20	2872.8	5.24	274.0	467122	0.30	0.03	3.07	0.07
BL4_21	2833.2	19.36	126.0	490089	1.17	1.57	78.31	6.07
BL4_22	2657.1	12.95	910.2	471929	1.09	0.02	17.57	0.31
BL4_23	2778.4	3.47	271.4	475104	0.71	0.02	3.54	0.05
BL4_24	2835.0	4.96	534.3	464962	1.10	0.01	11.48	0.04
BL4_25	1930.1	10.29	375.1	464810	1.12	0.49	22.91	1.35
BL4_26	2642.6	17.50	412.2	459693	2.32	2.56	80.53	3.13
BL4_27	2174.6	23.99	88.9	462513	3.40	4.61	86.67	10.02
BL4_28	2265.3	5.04	582.7	489338	1.34	0.02	4.37	0.10
BL4_29	2753.3	6.21	844.2	471165	3.29	0.01	21.99	0.06
BL4_30	2699.1	6.15	297.4	439635	1.34	0.02	15.68	0.06
BL4_31	2755.8	5.04	635.4	468379	1.69	0.01	6.12	0.05
BL4_32	3514.4	6.23	399.4	405763	0.45	0.28	12.52	0.63
BL4_33	3055.5	7.73	394.0	457085	0.77	0.02	6.63	0.04
BL4_34	3013.4	15.96	1067.3	453254	1.26	0.21	14.55	0.71
BL4_35	1822.4	180.77	92.3	498463	6.63	1.11	43.93	47.76
BL4_36	2718.0	6.41	417.2	445575	0.62	0.02	20.25	0.14
BL4_37	2743.7	22.00	317.0	436512	0.46	0.02	6.77	0.17
BL4_38	2712.4	6.32	152.7	468791	0.71	0.01	16.48	0.07
BL4_39	3012.0	13.31	251.1	425887	0.52	0.22	6.68	0.25
BL4_40	2725.0	15.24	231.0	469997	0.55	0.01	3.50	0.04
BL4_41	2597.4	8.06	144.3	440916	1.34	0.22	33.61	0.16
BL4_42	2146.8	26.08	715.7	570114	1.52	0.09	21.79	0.55
BL4_43	2081.6	15.38	526.9	475293	0.94	0.01	4.07	0.08
BL4_44	2061.5	4.59	620.5	428143	0.94	0.02	5.76	0.18
BL4_45	2718.6	16.70	250.8	433448	1.26	0.20	31.91	0.32
BL4_46	2735.7	7.16	472.7	432873	0.98	0.05	7.86	0.15
BL4_47	2729.5	19.86	225.4	499908	0.68	0.01	12.43	0.11
BL4_48	2665.9	260.20	109.3	519393	7.51	96.87	62.47	110.78
BL4_49	2701.1	146.95	128.2	487010	4.18	1.63	409.36	32.21
BL4_50	2147.1	18.23	1072.1	447621	0.83	0.02	9.73	0.23
BL4_51	2687.5	8.8	224.0	452594	1	0.01	20.5	0.17

Data Table 3. Zircon trace element values (ppm) for Bear Lake Lower (BL4) (CONT.)

Sample	Nd146	Sm147	Eu151	Eu153	Gd157	Tb159	Dy163	Ho165
BL4_1	0.70	1.72	0.56	0.58	7.83	2.81	35.14	12.54
BL4_2	0.68	1.40	0.33	0.33	6.17	2.31	28.42	10.08
BL4_3	0.69	1.37	0.50	0.53	6.1	2.3	29.39	10.82
BL4_4	0.62	1.25	0.71	0.75	4.66	1.55	15.94	4.98
BL4_5	1.06	2.08	0.68	0.66	8.71	2.85	34.02	11.66
BL4_6	2.11	3.96	0.82	0.86	15.18	5.10	60.09	21.10
BL4_7	0.70	1.48	0.49	0.47	5.78	1.97	23.66	8.57
BL4_8	1.41	2.75	0.58	0.57	10.81	3.45	41.97	13.83
BL4_9	0.56	1.27	0.23	0.23	5.69	2.41	34.15	13.03
BL4_10	1.57	2.74	0.81	0.81	7.56	2.31	24.49	7.45
BL4_11	0.76	1.26	0.30	0.31	4.88	1.45	15.91	5.25
BL4_12	0.85	1.80	0.39	0.37	7.81	2.87	34.15	12.26
BL4_13	3.97	5.72	1.38	1.44	20.11	6.43	76.41	22.69
BL4_14	3.01	4.78	1.13	1.17	19.81	6.47	76.03	24.12
BL4_15	16.02	25.67	11.18	12.26	55.64	15.37	135.13	31.93
BL4_16	0.74	1.26	0.21	0.22	5.98	2.20	28.07	10.16
BL4_17	73.82	82.81	26.42	28.70	126.91	35.73	301.52	61.39
BL4_18	0.49	1.08	0.37	0.41	4.43	1.61	19.38	7.22
BL4_19	1.47	3.09	0.23	0.26	16.34	6.00	78.07	28.56
BL4_20	0.55	1.21	0.49	0.54	4.89	1.73	21.84	8.29
BL4_21	35.99	41.64	13.10	14.48	70.40	19.64	173.17	38.83
BL4_22	3.34	4.96	1.06	1.21	19.37	6.57	79.92	26.78
BL4_23	0.35	0.78	0.22	0.25	4.05	1.66	22.43	8.35
BL4_24	0.42	1.15	0.24	0.22	6.74	2.58	37.68	14.70
BL4_25	8.46	10.76	3.02	3.41	19.11	5.43	52.47	13.53
BL4_26	13.10	8.80	1.65	1.91	28.03	8.81	101.53	31.75
BL4_27	61.31	69.39	20.38	23.05	131.72	39.15	403.31	104.86
BL4_28	1.20	2.25	0.24	0.27	10.53	3.73	47.10	16.98
BL4_29	1.04	2.33	0.39	0.40	12.30	4.44	58.65	21.53
BL4_30	0.57	1.23	0.24	0.18	5.55	2.03	25.95	9.36
BL4_31	0.63	1.46	0.23	0.24	8.71	3.26	45.65	17.25
BL4_32	4.50	5.30	1.67	2.10	11.20	3.40	35.18	10.94
BL4_33	0.51	0.97	0.41	0.43	5.52	2.18	30.68	11.56
BL4_34	5.82	10.21	2.88	3.04	35.38	11.51	131.10	43.95
BL4_35	522.76	799.17	392.91	419.46	1441.7	408.99	750.87	729.65
BL4_36	1.64	2.85	0.86	0.91	9.08	2.91	32.30	11.26
BL4_37	1.86	2.58	1.07	1.18	7.06	2.24	27.34	9.86
BL4_38	0.77	1.32	0.49	0.52	3.47	1.20	13.75	4.75
BL4_39	1.06	0.84	0.30	0.39	3.54	1.34	18.38	7.58
BL4_40	0.40	0.76	0.25	0.30	4.22	1.45	19.01	7.43
BL4_41	0.65	0.68	0.26	0.28	2.71	0.87	10.46	4.17
BL4_42	5.77	10.08	4.34	4.12	28.14	8.61	87.78	28.15
BL4_43	1.03	2.23	0.18	0.18	9.03	3.30	42.98	15.42
BL4_44	1.57	3.02	0.26	0.28	11.40	4.16	50.57	17.66
BL4_45	2.24	3.15	0.96	0.99	8.31	2.63	27.75	8.17
BL4_46	1.33	2.41	0.56	0.62	9.24	3.25	39.97	14.03
BL4_47	1.09	2.13	0.37	0.27	7.40	2.22	23.78	7.43
BL4_48	805.57	1123.5	518.76	559.54	2049.2	591.88	355.97	687.13
BL4_49	325.79	590.84	307.57	346.28	1049.7	291.26	2612.9	452.16
BL4_50	2.75	5.59	1.93	2.04	17.35	6.29	75.54	27.02
BL4_51	1.40	3.08	1.47	1.34	5.78	1.84	19.18	6.50

Data Table 3. Zircon trace element values (ppm) for Bear Lake Lower (BL4) (CONT.)

Sample	Er166	Tm169	Yb172	Lu175	Hf179	Ta181	Th232	U238
BL4_1	58.24	14.30	146.2	24.3	8415	0.43	57.5	144.6
BL4_2	44.78	10.53	104.7	17.2	8851	0.40	36.9	45.6
BL4_3	52.36	13.51	147.5	26.4	9507	0.31	8	22.9
BL4_4	18.37	3.97	36.3	6.0	7550	0.26	14.0	29.3
BL4_5	52.12	12.72	130.6	21.8	8493	0.32	52.3	71.7
BL4_6	97.18	23.35	244.3	43.7	10169	0.72	190.2	141.3
BL4_7	39.33	9.88	104.5	19.2	8516	0.25	32.5	44.3
BL4_8	60.50	13.89	144.4	21.9	8247	0.43	80.8	100.0
BL4_9	63.39	16.72	184.5	28.2	9274	1.33	65.7	105.1
BL4_10	30.13	7.13	72.6	11.5	8900	0.54	124.9	168.1
BL4_11	22.60	5.21	50.7	8.5	9303	0.24	55.3	81.9
BL4_12	56.10	13.52	142.0	23.8	9411	0.47	36.1	97.2
BL4_13	91.80	20.17	191.6	29.0	8098	0.42	32.7	33.3
BL4_14	100.01	21.41	197.3	30.8	8713	0.49	62.5	45.5
BL4_15	109.13	22.17	208.1	32.4	9544	0.43	134.4	168.4
BL4_16	46.07	10.88	110.5	17.4	10060	0.56	26.4	52.6
BL4_17	183.55	32.86	303.9	36.9	11255	0.60	128.2	341.0
BL4_18	34.47	8.86	96.4	18.4	9142	0.28	31.1	120.3
BL4_19	122.62	27.96	284.4	39.7	11171	1.02	110.4	109.7
BL4_20	39.31	10.03	104.5	20.9	8348	0.12	24.0	57.9
BL4_21	126.39	24.14	220.5	28.3	10563	0.43	258.2	251.0
BL4_22	113.48	25.41	246.0	39.0	8464	0.41	60.0	52.2
BL4_23	39.32	9.74	102.1	18.2	11628	0.36	30.1	104.6
BL4_24	71.27	17.63	189.3	32.2	9673	0.48	48.0	71.1
BL4_25	53.06	12.53	129.1	20.9	10149	0.51	255.5	342.1
BL4_26	130.49	28.31	287.3	39.5	8841	0.62	178.6	110.9
BL4_27	376.73	71.25	652.6	83.2	7460	1.12	150.3	327.6
BL4_28	72.80	16.26	154.8	25.4	10008	0.43	29.2	33.8
BL4_29	97.17	22.93	233.0	36.6	9468	1.20	76.2	187.8
BL4_30	41.19	9.69	97.0	14.4	9863	0.45	73.2	69.7
BL4_31	79.58	18.54	187.1	29.4	9148	0.70	28.2	71.3
BL4_32	48.02	12.22	147.5	24.2	7143	0.22	102.5	201.9
BL4_33	54.89	13.23	142.3	22.7	7596	0.31	23.1	36.8
BL4_34	190.67	35.70	286.1	60.9	7230	0.47	106.0	66.4
BL4_35	2043.4	297.21	2841.9	289.2	12375	2.34	846.5	1038.3
BL4_36	50.47	12.84	131.0	22.5	8352	0.21	35.9	52.5
BL4_37	45.36	11.71	123.9	23.0	9359	0.19	25.5	51.0
BL4_38	22.97	6.05	66.1	12.1	10231	0.46	56.6	116.8
BL4_39	39.08	10.51	118.1	22.7	8779	0.24	18.5	57.2
BL4_40	35.46	8.63	89.3	15.2	8046	0.19	17.1	35.6
BL4_41	21.88	6.39	79.1	17.9	10114	0.29	92.3	95.3
BL4_42	118.16	23.45	196.7	42.5	12757	0.69	140.1	111.1
BL4_43	67.44	15.85	158.6	23.4	9727	0.42	50.8	103.1
BL4_44	78.49	17.41	163.7	27.1	9205	0.41	94.2	132.3
BL4_45	32.02	7.00	68.0	9.9	8214	0.55	73.4	83.5
BL4_46	62.58	14.34	141.8	23.3	7688	0.53	66.9	124.3
BL4_47	30.54	6.76	60.4	10.4	11301	0.26	83.5	29.6
BL4_48	2125.8	465.67	2926.7	438.6	13982	1.37	1329.0	986.1
BL4_49	1204.9	175.03	1430.7	157.4	13930	1.81	1056.6	915.8
BL4_50	119.68	28.35	289.7	44.8	7812	0.29	87.7	146.1
BL4_51	30.36	8.02	87.0	15.3	10144	0.54	54.8	117.5

Data Table 4. Zircon trace element values (ppm) for Bear Lake Upper (BL6)

*Red text denotes discarded samples

Sample	207/206 Age	Ti49	Y89	Zr91	Nb93	La139	Ce140	Pr141
BL6_1	1800.6	4.84	315.8	468462	0.96	0.02	14.13	0.18
BL6_2	2027.6	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
BL6_3	3034.9	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
BL6_4	2673.7	6.81	861.0	486015	1.94	2.35	73.80	3.72
BL6_5	1854.2	12.56	1316.7	489382	1.16	0.04	16.93	0.55
BL6_6	1821.7	18.23	295.1	492906	1.27	0.01	54.24	0.19
BL6_7	1921.4	14.45	441.5	495629	1.79	0.01	40.67	0.15
BL6_8	2094.9	15.33	668.3	494449	1.08	0.01	6.68	0.14
BL6_9	2801.3	18.27	246.3	497728	0.62	0.01	13.71	0.07
BL6_10	2785.2	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
BL6_11	1837.5	6.92	164.3	486677	0.47	0.01	4.60	0.04
BL6_12	2214.3	15.36	781.6	495076	1.98	0.02	14.44	0.59
BL6_13	1857.1	9.25	267.7	493025	0.76	0.01	9.72	0.04
BL6_14	1929.5	15.38	1999.5	493430	1.42	0.01	11.11	0.43
BL6_15	1934.8	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
BL6_16	1848.4	5.97	205.2	493588	0.73	0.01	29.54	0.09
BL6_17	1849.7	5.40	472.2	494217	1.08	0.01	25.92	0.13
BL6_18	1822.1	7.75	422.4	491809	1.99	0.01	17.25	0.10
BL6_19	1821.4	13.60	722.3	506855	2.10	0.01	5.93	0.09
BL6_20	2937.8	7.01	184.7	506678	0.38	0.01	3.38	0.04
BL6_21	2672.2	9.84	499.0	500669	1.43	0.01	13.29	0.05
BL6_22	1824.9	6.64	213.4	499974	1.45	0.01	18.82	0.03
BL6_23	1911.1	8.73	462.5	491793	2.93	0.01	12.57	0.07
BL6_24	1853.9	16.48	1488.6	486710	2.97	0.01	40.83	0.63
BL6_25	2665.2	15.06	486.0	485773	1.85	0.01	5.27	0.06
BL6_26	2089.8	5.71	681.3	467854	3.59	0.36	19.67	1.06
BL6_27	2067.7	8.52	428.7	476249	1.79	0.01	19.89	0.10
BL6_28	2057.4	10.80	918.2	493767	1.82	0.01	15.09	0.35
BL6_29	1875.9	10.09	393.7	511741	1.26	0.05	12.53	0.23
BL6_30	2771.1	36.81	114.8	515705	4.75	0.49	48.93	6.33
BL6_31	2730.2	11.52	1003.1	525890	2.19	0.01	26.06	0.11
BL6_32	1833.0	12.43	431.3	511841	0.86	0.01	11.06	0.08
BL6_33	2670.3	8.06	412.5	500833	1.65	0.01	16.13	0.03
BL6_34	3937.3	155.01	182.9	568217	15.27	1.75	75.80	15.36
BL6_35	2705.3	11.40	1283.7	509380	2.79	1.00	54.26	5.75
BL6_36	2643.6	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
BL6_37	1847.9	14.81	488.3	534700	1.36	0.01	15.15	0.11
BL6_38	2682.8	9.49	413.5	561122	1.14	0.04	9.55	0.21
BL6_39	2684.5	16.44	722.6	542321	1.30	2.33	57.31	2.42
BL6_40	1840.0	21.60	661.2	555634	0.89	0.01	3.90	0.09
BL6_41	1902.7	15.54	344.5	523091	2.14	0.02	47.53	0.14
BL6_42	1915.4	7.19	391.8	529903	1.47	0.01	22.27	0.09
BL6_43	2304.8	13.34	939.9	537710	1.46	0.02	4.03	0.21
BL6_44	2553.2	4.78	1154.7	519116	0.85	0.01	4.18	0.11

Data Table 4. Zircon trace element values (ppm) for Bear Lake Upper (BL6) (CONT.)

Sample	Nd146	Sm147	Eu151	Eu153	Gd157	Tb159	Dy163	Ho165
BL6_1	1.58	1.97	0.37	0.39	7.25	2.35	28.89	9.80
BL6_2	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
BL6_3	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
BL6_4	14.19	5.64	1.15	1.06	13.64	4.54	58.13	20.99
BL6_5	5.07	6.80	1.96	2.08	21.32	7.46	93.16	33.65
BL6_6	2.00	3.23	0.95	0.95	9.66	2.73	29.47	9.34
BL6_7	1.75	3.37	0.69	0.76	11.68	3.70	42.15	13.46
BL6_8	1.71	2.97	0.24	0.25	12.43	4.30	53.85	18.87
BL6_9	0.73	1.32	0.38	0.41	5.38	1.86	22.94	7.97
BL6_10	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
BL6_11	0.34	0.67	0.26	0.31	2.93	0.95	12.67	5.26
BL6_12	6.48	9.36	1.06	1.10	31.06	10.34	118.99	38.69
BL6_13	0.41	0.93	0.21	0.21	3.58	1.49	20.29	7.73
BL6_14	5.43	9.01	0.61	0.64	34.14	11.24	132.64	42.80
BL6_15	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
BL6_16	0.91	1.44	0.51	0.50	5.17	1.56	18.46	6.15
BL6_17	1.28	2.27	0.51	0.53	9.05	3.05	38.19	13.39
BL6_18	1.00	1.86	0.27	0.30	7.77	2.76	35.80	12.95
BL6_19	0.90	2.16	0.18	0.15	10.75	4.03	54.12	19.75
BL6_20	0.25	0.62	0.24	0.25	3.03	1.15	15.07	5.68
BL6_21	0.69	1.43	0.30	0.32	7.34	2.96	39.44	14.69
BL6_22	0.38	0.94	0.25	0.26	3.58	1.28	17.05	6.51
BL6_23	0.75	1.65	0.13	0.15	7.50	2.81	37.65	13.87
BL6_24	7.95	11.83	2.40	2.51	37.85	11.01	124.47	37.83
BL6_25	0.67	1.50	0.25	0.26	7.96	3.00	40.36	14.66
BL6_26	4.58	3.34	0.23	0.24	12.30	4.22	56.58	19.75
BL6_27	1.16	1.99	0.40	0.44	7.92	2.65	35.09	12.91
BL6_28	3.61	5.11	0.30	0.33	17.73	5.63	72.84	24.93
BL6_29	1.53	2.44	0.54	0.54	6.97	2.48	30.78	11.31
BL6_30	61.81	139.66	46.51	46.49	266.52	69.09	575.22	113.47
BL6_31	1.44	2.86	0.46	0.46	14.03	5.06	70.46	26.30
BL6_32	0.97	1.82	0.65	0.64	7.94	2.84	37.30	13.11
BL6_33	0.40	1.02	0.15	0.14	5.51	2.18	32.03	12.03
BL6_34	145.65	418.53	115.02	113.63	1072.8	282.76	2523.6	429.95
BL6_35	38.49	47.94	13.97	14.39	77.7	20.88	179.74	40.22
BL6_36	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
BL6_37	1.42	2.56	0.39	0.41	10.61	3.50	42.83	15.00
BL6_38	1.56	2.28	0.56	0.63	7.12	2.63	33.46	12.27
BL6_39	10.55	6.35	1.76	1.86	18.11	5.40	62.98	21.33
BL6_40	1.28	2.72	0.31	0.32	11.82	4.00	52.06	18.51
BL6_41	1.56	2.46	0.71	0.64	8.37	2.66	32.89	10.81
BL6_42	1.20	2.00	0.36	0.35	7.93	2.76	34.01	12.41
BL6_43	2.45	3.85	0.68	0.76	15.78	5.53	71.05	24.87
BL6_44	1.70	3.29	1.01	1.00	16.47	6.13	83.39	30.25

Data Table 4. Zircon trace element values (ppm) for Bear Lake Upper (BL6) (CONT.)

Sample	Er166	Tm169	Yb172	Lu175	Hf179	Ta181	Th232	U238
BL6_1	42.58	10.09	96.1	16.6	9154	0.35	37.4	40.9
BL6_2	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
BL6_3	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
BL6_4	100.58	24.98	264.4	44.2	9584	0.77	187.8	273.4
BL6_5	153.22	35.60	356.7	59.1	8023	0.59	133.0	156.0
BL6_6	38.10	8.62	81.0	13.4	8442	0.40	68.4	63.4
BL6_7	56.18	12.61	118.3	19.4	9965	0.67	78.6	61.5
BL6_8	82.41	18.57	177.7	28.0	10122	0.47	66.1	62.6
BL6_9	35.95	8.45	82.6	14.6	8861	0.26	30.1	37.8
BL6_10	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
BL6_11	27.83	8.25	95.8	21.9	6916	0.14	36.6	108.8
BL6_12	159.79	34.82	342.5	48.5	8554	0.80	104.5	118.0
BL6_13	38.87	10.68	114.3	19.9	12418	0.45	51.2	234.6
BL6_14	176.49	37.19	341.5	50.7	10050	0.62	142.1	134.5
BL6_15	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
BL6_16	27.44	6.83	71.8	12.2	9299	0.26	52.2	88.8
BL6_17	60.07	14.84	149.4	24.0	8943	0.42	71.8	152.0
BL6_18	58.70	13.93	137.8	23.2	10194	0.86	59.7	73.3
BL6_19	86.32	19.97	194.2	30.5	10163	0.96	62.2	135.1
BL6_20	26.12	6.87	73.4	13.0	9521	0.17	13.4	53.7
BL6_21	67.91	16.40	162.8	27.4	10065	0.55	38.1	62.4
BL6_22	30.80	8.17	89.6	15.6	9250	0.68	35.3	62.3
BL6_23	63.41	15.24	148.8	25.1	11106	1.12	45.2	77.5
BL6_24	145.89	30.93	293.4	42.8	9263	0.90	73.0	50.2
BL6_25	64.55	14.82	139.9	22.5	9355	0.72	31.8	60.2
BL6_26	86.33	19.67	188.2	27.4	9409	1.39	95.9	258.4
BL6_27	61.67	15.43	157.5	28.5	10016	0.74	66.0	113.8
BL6_28	104.93	24.18	225.7	36.3	10324	0.55	42.9	42.4
BL6_29	54.10	13.93	145.4	26.1	11294	0.67	49.3	190.0
BL6_30	369.54	72.69	633.7	90.4	14246	1.59	545.7	558.4
BL6_31	118.12	28.00	267.9	48.5	12793	0.84	96.9	113.2
BL6_32	56.87	13.18	124.7	22.1	9847	0.38	58.3	74.4
BL6_33	54.67	13.00	126.4	21.8	11976	0.63	111.6	130.2
BL6_34	1143.4	170.53	1268.5	160.6	8801	0.67	456.3	1530.5
BL6_35	140.3	30.45	277.2	47.1	12528	1.46	226.3	198.4
BL6_36	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
BL6_37	63.24	14.17	131.4	24.1	10160	0.48	71.9	81.2
BL6_38	59.96	13.94	125.5	27.8	14677	0.70	91.2	161.1
BL6_39	90.96	19.11	150.6	39.7	11211	0.47	78.3	58.3
BL6_40	78.60	17.26	156.5	29.0	10624	0.36	31.4	48.0
BL6_41	45.84	10.06	92.9	17.7	10800	0.78	85.2	82.0
BL6_42	55.01	12.21	114.7	21.0	10812	0.47	82.0	72.7
BL6_43	106.39	22.22	199.0	35.5	9611	0.57	40.8	77.9
BL6_44	131.91	29.31	270.8	48.2	9494	0.29	37.2	77.9

Data Table 5. Zircon trace element values (ppm) for St. Peter Lower (S5)

*Red text denotes discarded samples

Sample	207/206 Age	Ti49	Y89	Zr91	Nb93	La139	Ce140	Pr141
S5_1	1047.6	8.14	228.1	512942	25.97	0.01	34.43	0.65
S5_2	1051.3	8.94	426.6	489742	4.00	0.02	14.41	1.03
S5_3	1079.4	10.86	312.8	483486	2.94	0.03	8.14	0.86
S5_4	1093.8	7.82	1106.9	494430	3.63	0.01	7.18	0.13
S5_5	1098.3	2.79	874.8	490991	1.72	0.01	5.73	0.24
S5_6	1098.6	14.07	118.1	474755	2.90	0.02	16.07	1.07
S5_7	1103.8	4.88	302.7	486640	6.60	0.01	23.65	0.28
S5_8	1108.2	6.40	861.7	446546	14.11	0.01	14.36	0.09
S5_9	1109.4	7.55	344.9	472264	11.88	0.01	17.10	0.53
S5_10	1114.5	7.58	157.6	482753	5.51	0.02	20.06	1.02
S5_11	1126.9	6.30	902.9	483486	6.72	0.01	13.76	0.12
S5_12	1134.5	12.41	396.4	482661	4.33	0.03	8.96	0.96
S5_13	1833.5	18.16	801.6	480295	2.39	0.01	8.34	0.15
S5_14	1847.3	14.62	1849.7	479372	2.88	0.01	16.54	0.08
S5_15	1852.0	22.02	403.5	482950	1.64	0.01	24.94	0.12
S5_16	1880.8	11.55	543.1	479955	1.18	0.01	10.53	0.08
S5_17	1924.5	22.26	315.5	489400	1.18	0.01	16.00	0.13
S5_18	2456.0	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
S5_19	2666.6	9.38	1623.2	452266	1.49	0.01	9.37	0.12
S5_20	1075.7	18.39	1745.2	478125	0.95	0.01	4.65	0.41
S5_21	2682.9	6.91	1227.8	463440	1.51	0.01	3.16	0.09
S5_22	2692.0	5.18	1009.5	484349	3.65	0.01	46.46	0.08
S5_23	2696.5	5.91	1076.8	497587	2.45	0.01	6.57	0.08
S5_24	2697.9	6.76	1513.0	501708	2.20	0.01	33.31	0.16
S5_25	2699.6	5.11	547.1	483714	1.31	0.01	4.30	0.08
S5_26	2702.7	13.42	892.8	483454	0.70	0.01	25.01	0.35
S5_27	2707.1	17.14	581.5	498928	1.09	0.01	34.55	0.23
S5_28	2710.7	6.82	388.2	489706	0.52	0.01	22.66	0.75
S5_29	2710.7	24.19	416.2	503274	1.23	0.01	23.86	0.18
S5_30	2714.4	16.73	479.3	488076	0.99	0.01	34.89	0.16
S5_31	2715.0	4.89	662.4	445211	0.90	0.01	21.97	0.04
S5_32	2715.9	7.64	828.8	518736	1.01	0.01	19.63	0.16
S5_33	2720.5	6.72	312.0	485223	0.58	0.00	7.45	0.05
S5_34	2731.0	4.11	154.2	479769	0.64	0.01	4.72	0.05
S5_35	2731.0	3.90	281.2	481563	0.54	0.01	4.29	0.03
S5_36	2737.4	9.70	563.8	492447	0.76	0.01	6.65	0.04
S5_37	2739.2	6.15	638.9	500789	0.72	0.01	3.92	0.03
S5_38	2743.9	8.69	500.0	489612	1.13	0.01	8.09	0.24
S5_39	2746.5	12.87	1634.6	506830	0.86	0.01	8.11	0.32
S5_40	1865.9	6.80	176.7	493208	0.51	0.01	4.27	0.04
S5_41	2696.2	16.46	882.8	493667	2.33	0.01	45.54	0.20
S5_42	2752.1	5.15	835.0	500157	1.27	0.01	15.32	0.11
S5_43	2769.8	6.94	149.7	510950	1.34	0.01	9.82	0.30
S5_44	2790.6	16.74	260.9	503297	0.95	0.01	19.91	0.15
S5_45	2818.8	15.52	542.0	448650	1.13	0.01	35.09	0.19
S5_46	2825.4	5.37	1668.7	477780	2.99	0.01	18.96	0.09
S5_47	2827.4	9.04	887.9	503281	1.25	0.01	22.03	0.11
S5_48	2899.3	14.08	651.9	509601	0.86	0.06	34.00	0.92
S5_49	2926.2	8.83	558.8	503516	1.20	0.01	6.13	0.21
S5_50	3178.2	117.53	245.2	475318	2.93	0.59	74.99	12.93
S5_51	3261.1	108.8	369.9	458281	2.29	0.42	60.9	10.58

Data Table 5. Zircon trace element values (ppm) for St. Peter Lower (S5) (CONT.)

Sample	Nd146	Sm147	Eu151	Eu153	Gd157	Tb159	Dy163	Ho165
S5_1	6.01	10.55	1.42	1.46	42.19	15.77	203.82	68.13
S5_2	11.27	15.58	0.51	0.52	62.47	20.97	246.04	81.34
S5_3	9.04	13.18	0.89	0.91	58.8	20.7	251.88	83.90
S5_4	1.95	3.66	0.33	0.35	16.79	6.75	87.21	30.69
S5_5	2.87	5.44	0.39	0.39	23.96	10.82	154.11	57.85
S5_6	10.61	14.03	1.38	1.52	53.26	19.16	238.71	84.14
S5_7	4.24	10.68	1.50	1.53	54.06	19.99	248.25	84.57
S5_8	1.26	2.23	0.24	0.25	10.46	4.44	61.73	23.66
S5_9	6.34	10.71	0.85	0.93	42.12	15.99	201.18	70.27
S5_10	13.92	25.12	2.30	2.36	99.61	32.14	372.07	117.78
S5_11	1.51	2.43	0.25	0.30	11.58	4.63	62.02	23.94
S5_12	9.84	13.96	0.92	0.92	56.23	19.06	223.92	72.95
S5_13	1.75	3.64	0.33	0.33	15.94	5.75	66.72	22.42
S5_14	1.00	2.57	0.55	0.53	15.43	7.25	106.99	42.38
S5_15	1.60	3.24	0.70	0.71	12.27	3.72	39.92	12.30
S5_16	0.97	2.21	0.24	0.24	11.48	3.76	45.78	15.90
S5_17	1.44	2.72	0.49	0.53	9.73	3.05	33.06	10.45
S5_18	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
S5_19	1.47	4.86	0.53	0.58	27.09	10.66	135.02	48.14
S5_20	3.80	7.06	2.09	2.25	32.35	11.45	141.10	48.56
S5_21	0.75	1.47	0.45	0.40	6.16	3.31	60.92	26.89
S5_22	1.02	2.68	0.49	0.41	14.15	5.18	67.07	25.37
S5_23	1.14	3.44	0.30	0.22	18.53	6.69	82.64	28.97
S5_24	2.02	4.31	0.54	0.53	23.42	8.06	100.92	36.22
S5_25	0.76	1.75	0.19	0.16	9.98	3.57	45.35	15.71
S5_26	4.72	6.32	1.38	1.32	24.68	6.77	76.08	24.58
S5_27	2.56	4.22	0.80	0.81	15.70	4.58	50.47	16.56
S5_28	8.19	8.46	3.82	3.73	22.24	4.99	43.69	11.76
S5_29	2.38	3.75	0.59	0.61	13.00	3.47	37.84	12.26
S5_30	2.36	4.41	0.89	0.80	15.96	4.27	44.57	14.05
S5_31	0.73	1.54	0.77	0.67	9.53	3.12	42.05	17.62
S5_32	2.73	4.69	1.11	1.11	19.07	5.53	64.93	21.98
S5_33	0.75	1.35	0.60	0.58	5.86	1.93	24.55	8.98
S5_34	0.70	0.85	0.28	0.25	2.61	0.89	11.88	4.61
S5_35	0.32	0.67	0.24	0.21	3.55	1.26	18.22	7.69
S5_36	0.42	1.34	0.27	0.21	7.79	3.01	42.91	16.66
S5_37	0.58	1.57	0.46	0.47	9.63	3.64	49.93	18.57
S5_38	3.22	8.46	2.25	2.37	47.38	16.76	217.30	76.30
S5_39	4.18	7.66	1.30	1.30	32.50	10.31	120.91	39.75
S5_40	0.41	0.67	0.31	0.28	2.77	0.99	13.30	5.21
S5_41	2.36	4.45	1.24	1.32	17.87	5.91	72.50	24.93
S5_42	1.87	4.86	0.22	0.20	20.48	6.37	75.50	24.92
S5_43	3.60	8.06	1.43	1.61	44.90	17.81	249.70	90.50
S5_44	1.78	3.34	0.90	0.93	11.52	3.20	31.43	8.18
S5_45	2.14	3.73	0.92	0.99	13.22	4.23	50.00	16.80
S5_46	1.07	4.27	0.40	0.42	21.42	8.37	110.25	38.54
S5_47	1.38	3.47	0.50	0.49	15.45	5.42	69.07	24.50
S5_48	5.76	7.60	2.02	2.18	16.54	5.77	64.01	18.99
S5_49	2.92	7.51	1.31	1.35	41.95	16.95	225.66	80.49
S5_50	73.42	65.50	9.37	10.20	114.65	39.92	438.76	113.68
S5_51	63.52	67.04	11.64	12.68	118.78	41.97	445.74	113.06

Data Table 5. Zircon trace element values (ppm) for St. Peter Lower (S5) (CONT.)

Sample	Er166	Tm169	Yb172	Lu175	Hf179	Ta181	Th232	U238
S5_1	286.77	58.60	526.3	74.4	7748	7.70	237.9	318.0
S5_2	333.63	69.78	639.4	103.5	6587	2.04	96.8	103.8
S5_3	338.35	69.84	616.0	93.5	7039	2.26	120	177.3
S5_4	134.05	30.25	270.8	43.8	8295	1.80	40.3	81.9
S5_5	270.86	63.05	609.9	90.7	5928	1.21	58.5	138.9
S5_6	377.10	80.30	746.9	114.2	8355	2.06	261.1	329.5
S5_7	342.88	67.42	543.5	76.1	6269	3.39	85.3	180.1
S5_8	114.62	28.40	275.1	46.0	9741	6.92	127.6	307.5
S5_9	308.94	68.51	634.0	94.7	9355	7.27	149.4	294.6
S5_10	461.21	90.97	781.6	111.9	6872	2.47	164.1	205.6
S5_11	119.08	29.39	283.1	47.5	8548	5.10	256.8	501.3
S5_12	295.56	61.37	552.1	86.7	7299	2.95	115.2	168.9
S5_13	94.34	20.94	189.8	31.9	10372	0.97	167.1	226.4
S5_14	211.27	53.21	562.4	104.5	11137	2.74	72.0	446.0
S5_15	49.01	10.82	98.3	17.1	8860	0.82	124.4	169.2
S5_16	70.82	16.15	156.3	28.1	10812	0.59	103.6	99.1
S5_17	42.01	9.42	85.6	14.1	10173	0.57	64.2	94.8
S5_18	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
S5_19	207.88	46.90	449.3	71.5	10289	0.67	95.5	207.1
S5_20	207.96	45.57	429.3	71.0	7891	0.53	55.8	75.9
S5_21	158.67	41.43	379.8	55.0	12315	0.54	53.9	237.9
S5_22	121.32	29.91	301.2	53.8	11451	1.56	143.1	116.2
S5_23	126.23	28.86	273.2	46.9	12256	1.30	141.8	298.9
S5_24	163.14	37.74	364.5	63.8	11431	0.79	162.5	102.4
S5_25	69.23	16.08	155.2	26.6	11812	0.75	66.0	191.4
S5_26	102.43	22.38	207.3	34.1	9344	0.40	133.3	120.9
S5_27	71.42	16.18	153.7	26.8	9230	0.51	111.9	117.6
S5_28	43.02	9.32	89.5	15.9	7676	0.32	370.1	132.2
S5_29	51.45	11.95	116.5	20.7	8428	0.58	161.0	159.9
S5_30	56.63	12.71	117.4	20.0	9412	0.50	159.4	187.4
S5_31	89.98	23.65	267.7	52.9	10770	0.40	130.5	282.1
S5_32	97.12	23.16	226.9	42.5	10548	0.55	152.0	146.3
S5_33	44.06	11.30	122.6	25.2	9621	0.37	42.1	78.8
S5_34	25.11	7.31	87.1	18.6	12293	0.74	46.0	174.5
S5_35	42.22	12.33	145.6	32.4	11733	0.40	35.7	89.7
S5_36	77.85	18.99	183.8	32.9	10184	0.48	23.5	39.3
S5_37	85.62	19.97	196.3	34.4	10130	0.37	13.0	30.1
S5_38	324.17	67.74	637.3	102.4	8158	0.50	70.4	85.7
S5_39	162.27	33.59	296.6	49.1	9478	0.54	46.8	50.9
S5_40	26.26	7.35	85.6	17.3	9063	0.29	17.9	76.4
S5_41	109.11	24.91	239.6	41.2	9096	0.88	76.9	54.1
S5_42	101.09	22.08	202.7	32.4	8688	0.66	115.7	193.6
S5_43	406.74	85.88	855.4	135.1	8731	0.82	164.1	195.8
S5_44	28.57	5.61	42.7	6.8	9692	0.35	128.6	170.0
S5_45	72.12	16.03	145.2	25.7	8531	0.55	171.7	152.5
S5_46	167.69	36.76	358.5	54.8	10628	1.73	210.0	415.5
S5_47	110.79	24.39	228.0	42.0	9622	0.57	121.9	104.6
S5_48	79.30	18.39	178.0	30.9	10656	0.29	188.2	229.7
S5_49	356.77	76.18	710.5	119.7	9188	0.69	63.7	81.1
S5_50	431.12	89.22	775.6	109.2	9607	0.68	501.2	459.0
S5_51	434.17	89.80	775.2	109.8	7454	0.42	418.7	380.3

Data Table 6. Zircon trace element values (ppm) for St. Peter Upper (AS2)

*Red text denotes discarded samples

Sample	207/206 Age	Ti49	Y89	Zr91	Nb93	La139	Ce140	Pr141
AS2_1	1001.5	22.22	884.5	488175	1.76	0.18	15.80	0.41
AS2_2	1011.2	3.36	245.3	467785	1.04	0.01	1.87	0.02
AS2_3	1135.7	31.22	600.8	491462	1.53	0.02	7.10	0.67
AS2_4	1049.0	6.60	799.4	511201	4.90	0.06	95.43	0.48
AS2_5	1059.6	8.18	856.3	494624	1.92	0.01	13.98	0.08
AS2_6	1092.3	9.18	777.8	491449	1.56	0.01	11.36	0.05
AS2_7	1196.8	7.19	591.3	499238	0.75	0.01	18.02	0.37
AS2_8	1108.8	13.80	380.2	507688	0.85	0.01	20.73	0.18
AS2_9	1121.8	17.51	1119.6	478180	2.22	0.01	9.47	0.29
AS2_10	1126.1	29.78	605.2	490457	1.01	0.01	33.32	0.25
AS2_11	1145.4	16.29	1550.6	462188	2.46	0.01	8.75	0.14
AS2_12	1145.5	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
AS2_13	1146.0	4.67	95.8	487193	2.15	0.02	17.44	0.54
AS2_14	1148.2	11.11	97.0	481594	2.02	0.01	11.28	0.36
AS2_15	1171.7	20.35	1576.1	489725	1.80	0.01	17.32	0.17
AS2_16	1190.3	55.46	144.9	442531	4.48	0.23	115.32	14.43
AS2_17	1196.1	8.77	1454.4	492240	2.01	0.01	12.20	0.09
AS2_18	1082.0	10.06	808.9	465229	2.29	0.04	7.23	2.15
AS2_19	1887.3	111.08	173.0	488063	7.72	0.51	270.69	37.95
AS2_20	2807.2	8.40	932.7	473040	0.83	0.01	15.02	0.34
AS2_21	2768.8	6.00	356.4	507438	0.61	0.01	6.32	0.04
AS2_22	2718.4	9.61	851.1	501241	1.03	0.01	12.79	0.07
AS2_23	2678.2	11.18	598.2	500202	0.96	0.01	35.45	0.16
AS2_24	2756.3	13.68	895.1	486680	0.98	0.01	11.55	0.09
AS2_25	2681.0	13.36	582.7	493332	0.90	0.01	8.26	0.12
AS2_26	2807.7	4.90	1363.8	494641	0.93	0.01	8.23	0.08
AS2_27	2701.7	10.81	227.2	493907	19.61	0.31	126.30	9.04
AS2_28	2729.3	11.66	418.5	495648	1.25	0.01	13.48	0.18
AS2_29	2715.9	7.96	1404.6	471834	2.19	0.01	54.70	0.19
AS2_30	2536.0	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
AS2_31	2723.4	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
AS2_32	2690.1	17.46	803.9	505616	0.89	0.02	31.21	0.26
AS2_33	2625.7	13.69	405.2	491984	1.32	0.01	41.49	0.13
AS2_34	2739.3	9.75	1577.7	494701	1.16	0.01	8.51	0.13
AS2_35	2686.8	5.52	525.4	558436	0.85	0.02	2.51	0.27
AS2_36	2950.9	8.66	480.4	480065	0.66	0.01	8.31	0.05
AS2_37	2697.1	13.09	1571.4	480722	1.00	0.03	31.62	0.72
AS2_38	2630.2	22.71	1365.1	490905	0.96	0.03	14.92	0.75
AS2_39	2986.6	6.31	537.6	436621	0.86	0.01	7.28	0.04
AS2_40	2711.3	5.02	145.7	508525	0.38	0.01	3.45	0.05
AS2_41	2718.0	7.07	1712.4	489873	0.89	0.01	6.55	0.10
AS2_42	2726.4	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
AS2_43	2656.1	15.97	577.0	485197	1.00	0.01	9.46	0.16
AS2_44	2731.8	9.51	871.7	494989	1.40	0.01	21.23	0.16
AS2_45	2735.1	11.32	598.3	448015	0.71	0.01	8.68	0.10
AS2_46	2737.4	10.01	576.0	523470	0.78	0.01	14.02	0.09
AS2_47	2761.6	5.80	876.1	447026	0.73	0.01	7.54	0.11

Data Table 6. Zircon trace element values (ppm) for St. Peter Upper (AS2) (CONT.)

Sample	Nd146	Sm147	Eu151	Eu153	Gd157	Tb159	Dy163	Ho165
AS2_1	2.41	3.87	0.68	0.71	16.44	5.49	68.57	23.53
AS2_2	0.35	1.10	0.27	0.27	7.48	2.21	25.75	7.96
AS2_3	6.88	11.60	1.53	1.68	43.4	12.9	150.20	48.06
AS2_4	4.89	8.33	1.97	2.18	31.52	9.90	119.08	39.80
AS2_5	0.84	2.41	0.40	0.44	12.21	4.81	63.48	21.90
AS2_6	0.66	1.89	0.25	0.27	9.47	3.82	54.45	20.63
AS2_7	4.23	8.75	2.14	2.26	31.85	10.07	131.52	47.70
AS2_8	2.13	3.39	1.18	1.27	12.49	3.36	37.10	11.48
AS2_9	3.74	8.80	1.20	1.37	31.67	9.85	111.32	34.73
AS2_10	2.92	6.55	1.94	1.86	27.89	9.76	130.70	47.94
AS2_11	1.64	4.05	0.37	0.37	20.73	7.58	98.75	36.31
AS2_12	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
AS2_13	5.38	11.06	1.22	1.31	48.70	17.03	224.31	80.74
AS2_14	4.38	10.39	1.26	1.34	53.85	18.55	242.08	85.46
AS2_15	2.01	4.80	0.52	0.56	21.68	7.90	100.89	36.19
AS2_16	116.46	174.64	57.99	58.04	251.17	67.10	621.32	154.55
AS2_17	1.07	3.00	0.48	0.50	15.37	6.64	93.87	37.40
AS2_18	25.71	55.56	7.98	8.22	74.14	18.91	143.12	25.88
AS2_19	398.41	727.77	120.10	130.58	1037.0	278.75	2609.7	474.20
AS2_20	3.25	5.60	2.06	2.16	22.15	6.71	76.18	24.67
AS2_21	0.52	1.04	0.27	0.29	5.28	1.96	26.62	10.66
AS2_22	0.98	2.65	0.50	0.48	12.28	4.70	62.46	22.62
AS2_23	2.04	4.19	1.39	1.31	15.36	4.57	50.79	16.43
AS2_24	1.31	3.06	0.64	0.62	14.53	5.32	67.85	23.78
AS2_25	1.68	4.99	0.45	0.39	20.98	5.86	59.05	17.80
AS2_26	1.17	3.50	1.24	1.25	20.80	8.21	121.56	49.82
AS2_27	79.41	74.24	31.33	31.00	159.90	36.57	329.27	80.84
AS2_28	2.47	6.29	0.63	0.66	31.07	11.69	158.69	57.66
AS2_29	2.60	6.18	1.18	1.16	21.92	7.51	93.49	32.74
AS2_30	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
AS2_31	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
AS2_32	3.53	7.00	1.45	1.48	24.90	6.94	72.10	21.28
AS2_33	1.86	3.48	0.78	0.72	12.03	3.46	36.17	11.50
AS2_34	1.35	3.36	0.73	0.75	18.22	6.80	94.51	36.40
AS2_35	3.19	9.99	1.01	0.99	40.41	15.06	181.59	50.61
AS2_36	0.67	1.42	0.51	0.59	6.76	2.43	33.92	13.66
AS2_37	8.92	14.19	1.87	2.03	46.59	13.27	145.98	45.38
AS2_38	7.21	10.16	1.93	2.05	37.76	11.16	127.72	38.99
AS2_39	0.48	1.20	0.29	0.27	6.40	2.60	37.52	15.66
AS2_40	0.70	1.53	0.65	0.63	5.87	1.62	16.40	4.51
AS2_41	1.39	3.41	0.68	0.70	20.48	7.94	110.69	41.85
AS2_42	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
AS2_43	1.98	3.97	0.37	0.36	14.06	4.33	51.14	17.17
AS2_44	1.82	3.64	0.66	0.68	14.77	4.94	63.42	22.59
AS2_45	0.94	2.37	0.45	0.50	10.79	4.01	49.19	18.04
AS2_46	1.15	2.44	0.64	0.67	11.17	3.63	46.33	16.83
AS2_47	1.66	3.90	0.78	0.73	16.18	5.34	66.87	24.16

Data Table 6. Zircon trace element values (ppm) for St. Peter Upper (AS2) (CONT.)

Sample	Er166	Tm169	Yb172	Lu175	Hf179	Ta181	Th232	U238
AS2_1	99.32	22.93	219.6	36.1	9551	0.72	35.3	46.7
AS2_2	30.58	6.33	59.2	9.7	11648	0.61	25.7	408.5
AS2_3	190.89	40.09	362.5	57.1	8925	0.75	34	77.4
AS2_4	163.91	35.62	351.3	52.0	9407	1.72	225.3	171.6
AS2_5	92.59	19.84	178.7	28.8	10839	1.03	107.1	354.8
AS2_6	97.74	23.95	244.7	42.7	11325	1.01	94.8	283.6
AS2_7	215.76	49.31	498.0	84.3	10150	0.35	121.4	169.4
AS2_8	46.62	10.78	112.8	18.3	9914	0.37	76.4	94.0
AS2_9	128.69	27.03	259.2	35.3	8981	0.84	41.4	77.6
AS2_10	210.77	45.25	395.5	79.1	9113	0.45	79.7	70.3
AS2_11	158.30	35.35	343.2	53.6	10077	1.06	75.3	175.5
AS2_12	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
AS2_13	349.97	77.00	776.1	116.1	9036	0.93	169.3	234.4
AS2_14	349.06	72.04	689.9	97.8	9824	1.19	138.5	168.4
AS2_15	160.31	36.97	367.6	59.0	9902	0.88	94.6	182.6
AS2_16	540.48	107.32	1001.1	134.0	10248	2.52	300.6	578.5
AS2_17	178.65	43.70	454.4	76.0	11158	0.64	24.2	52.3
AS2_18	68.34	10.62	73.9	9.4	13282	0.55	109.4	436.8
AS2_19	1366.6	215.38	1852.9	230.5	11475	2.17	885.0	1005.6
AS2_20	101.20	23.03	224.4	37.8	7837	0.36	86.8	92.9
AS2_21	52.55	13.35	142.0	27.9	10424	0.35	37.4	83.8
AS2_22	103.30	23.66	224.7	40.0	10671	0.60	41.7	61.7
AS2_23	71.60	17.03	169.5	31.3	9734	0.41	95.0	91.9
AS2_24	105.32	23.73	228.9	36.0	9156	0.70	58.8	76.3
AS2_25	68.31	14.10	121.2	20.6	11713	0.38	80.8	207.6
AS2_26	248.68	60.91	652.7	121.4	9537	0.31	60.6	135.2
AS2_27	263.81	47.78	386.5	54.0	9527	5.79	785.9	234.4
AS2_28	252.26	57.16	563.9	90.0	10280	0.69	46.0	57.8
AS2_29	149.71	35.20	348.8	62.3	11098	0.62	153.3	91.4
AS2_30	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
AS2_31	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
AS2_32	85.68	17.54	158.9	27.4	9594	0.43	129.3	149.9
AS2_33	47.87	10.93	103.9	19.6	10185	0.64	189.1	183.2
AS2_34	170.57	39.85	404.8	72.0	8776	0.64	74.4	120.1
AS2_35	179.96	31.41	213.8	39.8	15514	0.71	110.3	295.7
AS2_36	66.61	16.95	177.0	35.4	8352	0.29	18.4	26.2
AS2_37	180.75	36.93	337.4	54.0	9503	0.62	198.2	191.2
AS2_38	154.41	31.75	285.1	47.4	7879	0.55	116.6	93.9
AS2_39	78.05	19.62	203.4	41.8	9660	0.55	98.4	175.2
AS2_40	16.83	3.32	28.3	4.6	10559	0.13	11.3	24.0
AS2_41	190.01	43.37	426.1	71.9	9285	0.54	34.2	63.4
AS2_42	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
AS2_43	70.76	15.52	145.9	24.9	9771	0.40	60.2	70.4
AS2_44	103.92	24.68	247.4	43.6	10515	0.88	178.5	216.5
AS2_45	78.53	17.04	168.9	27.4	10484	0.34	27.2	54.4
AS2_46	76.44	17.41	177.2	31.3	9789	0.47	42.2	58.9
AS2_47	108.20	24.83	249.5	43.5	9256	0.45	55.9	93.9

Data Table 7. Zircon trace element values (ppm) for Basal Calico Rock (BC)

*Red text denotes discarded samples

Sample	207/206 Age	Ti49	Y89	Zr91	Nb93	La139	Ce140	Pr141
BC_1	1010.4	6.93	117.5	497633	6.07	0.01	24.90	0.09
BC_2	1048.6	5.84	632.0	490609	2.42	0.00	5.68	0.05
BC_3	1022.1	5.54	827.3	485720	2.50	0.01	5.75	0.06
BC_4	1053.5	8.70	614.3	454778	1.83	0.05	25.83	0.62
BC_5	1054.7	9.45	617.5	491962	1.86	0.01	25.72	0.08
BC_6	1032.2	6.11	304.3	496895	12.72	0.01	8.27	0.17
BC_7	1048.3	9.42	98.2	482686	30.44	0.01	59.70	0.08
BC_8	3555.9	95.26	102.7	502527	5.15	0.81	139.03	28.72
BC_9	1081.0	11.79	489.6	497561	3.20	0.01	31.46	0.27
BC_10	1016.0	7.72	518.4	492254	1.16	0.01	22.81	0.10
BC_11	1074.8	6.54	426.4	527716	1.25	0.01	11.76	0.25
BC_12	2695.5	12.42	264.0	495466	0.97	0.01	24.74	0.08
BC_13	1118.4	18.12	814.7	499064	3.06	0.02	41.06	0.10
BC_14	1034.2	9.61	694.1	509629	2.92	0.01	18.48	0.13
BC_15	1150.7	4.13	1425.1	494537	1.39	0.02	7.28	0.29
BC_16	1164.3	11.70	692.7	486419	0.49	0.01	14.50	0.25
BC_17	1076.0	7.95	1455.5	482275	1.61	0.03	13.51	0.47
BC_18	974.5	3.78	1110.1	482398	2.94	0.01	9.27	0.07
BC_19	1176.5	5.58	540.9	491262	2.59	0.01	21.41	0.06
BC_20	1042.0	6.27	662.4	484456	2.48	0.10	7.13	0.25
BC_21	2546.7	5.20	117.0	502429	0.52	0.01	2.09	0.05
BC_22	2685.0	37.40	72.7	501100	2.74	0.11	55.41	6.45
BC_23	1871.6	9.56	404.2	490312	0.60	0.00	4.67	0.05
BC_24	1221.4	6.95	867.8	505144	2.59	0.02	18.91	0.47
BC_25	1159.3	38.64	197.3	499901	2.26	0.01	8.45	0.16
BC_26	2623.7	12.02	244.0	498568	1.13	0.00	12.26	0.06
BC_27	2652.7	4.86	305.1	509508	0.68	0.01	2.48	0.16
BC_28	2689.5	13.57	174.3	533130	0.65	0.00	12.31	0.05
BC_29	2737.7	7.15	970.1	512411	0.71	0.00	7.94	0.05
BC_30	2833.5	10.34	607.8	501797	1.21	0.00	7.41	0.04
BC_31	2000.3	7.47	932.7	487371	3.06	9.34	327.98	16.90
BC_32	1060.1	14.15	437.2	500140	0.51	0.06	17.91	1.53

Data Table 7. Zircon trace element values (ppm) for Basal Calico Rock (BC) (CONT.)

Sample	Nd146	Sm147	Eu151	Eu153	Gd157	Tb159	Dy163	Ho165
BC_1	1.34	2.78	0.30	0.30	16.97	7.20	103.46	40.78
BC_2	0.59	1.63	0.17	0.17	10.50	4.46	63.68	24.38
BC_3	0.79	1.93	0.13	0.14	10.7	4.3	57.25	20.82
BC_4	4.74	4.64	1.00	1.04	12.06	4.02	46.94	15.73
BC_5	1.02	2.33	0.55	0.53	12.45	4.17	49.48	16.07
BC_6	2.38	4.80	3.35	3.42	24.71	9.59	118.15	38.84
BC_7	1.16	3.21	0.36	0.36	20.81	9.35	132.53	50.25
BC_8	211.16	180.30	29.75	31.45	290.89	76.20	672.18	150.37
BC_9	2.38	2.71	0.55	0.58	8.18	3.07	38.50	13.57
BC_10	1.15	1.96	0.62	0.63	8.73	3.15	39.67	14.58
BC_11	2.70	4.59	1.08	1.06	20.29	7.58	93.49	31.86
BC_12	1.03	1.71	0.42	0.42	6.75	2.08	23.01	7.72
BC_13	1.26	2.51	0.62	0.65	12.42	4.66	59.09	20.34
BC_14	1.60	2.87	0.54	0.57	11.79	4.23	53.10	18.56
BC_15	3.32	5.36	0.62	0.65	21.96	8.16	103.21	35.17
BC_16	2.67	3.91	0.83	0.88	14.97	4.77	55.20	18.83
BC_17	4.74	6.60	1.15	1.30	25.21	8.82	106.22	35.00
BC_18	0.80	2.05	0.29	0.32	11.81	5.01	69.83	26.25
BC_19	0.73	2.00	0.18	0.18	12.47	5.68	84.02	33.12
BC_20	2.35	4.02	0.66	0.71	16.67	5.58	62.15	19.56
BC_21	0.69	1.53	0.34	0.34	5.99	1.74	14.77	3.66
BC_22	52.06	63.87	9.02	9.22	102.34	26.84	242.34	60.66
BC_23	0.61	1.37	0.37	0.35	6.03	2.24	29.56	11.44
BC_24	3.44	5.21	1.07	1.04	14.42	5.15	65.31	23.08
BC_25	2.04	6.06	1.09	1.09	31.34	11.87	158.55	57.49
BC_26	0.82	2.31	0.21	0.24	8.60	2.68	27.00	7.83
BC_27	1.53	2.51	0.38	0.41	8.92	3.50	35.90	9.13
BC_28	0.62	1.12	0.44	0.43	4.13	1.35	15.15	5.33
BC_29	0.91	2.66	0.49	0.48	13.23	5.10	66.15	24.42
BC_30	0.59	1.52	0.27	0.28	8.69	3.38	45.22	17.44
BC_31	65.84	20.06	1.02	1.09	32.54	8.96	97.54	33.25
BC_32	11.35	12.87	2.26	2.37	21.00	5.78	48.04	12.09

Data Table 7. Zircon trace element values (ppm) for Basal Calico Rock (BC) (CONT.)

Sample	Er166	Tm169	Yb172	Lu175	Hf179	Ta181	Th232	U238
BC_1	196.45	48.31	514.4	87.9	11804	2.51	189.6	343.6
BC_2	121.51	31.79	344.7	62.0	13339	1.63	207.6	443.9
BC_3	93.43	21.61	211.0	36.6	12298	1.02	56	174.9
BC_4	74.06	17.96	180.2	31.8	11073	1.14	96.8	356.9
BC_5	67.84	14.82	135.5	23.0	11043	0.85	86.4	118.1
BC_6	161.95	33.90	294.0	43.4	5450	5.50	372.6	330.2
BC_7	239.12	56.12	561.6	92.6	14230	14.04	75.8	244.7
BC_8	537.26	106.40	1013.8	148.6	12472	3.04	315.0	2525.7
BC_9	64.84	16.43	169.4	30.1	12589	1.91	85.9	246.5
BC_10	68.29	16.10	160.7	30.5	10002	0.41	31.6	61.4
BC_11	138.73	30.76	297.5	48.3	10350	0.64	74.2	124.3
BC_12	34.64	8.05	75.9	14.1	10771	0.51	100.7	91.9
BC_13	92.40	21.67	208.9	35.8	11074	1.51	87.7	134.8
BC_14	82.78	19.40	183.4	31.7	10802	0.89	72.9	86.7
BC_15	155.18	33.19	302.8	49.7	8468	0.52	48.9	60.0
BC_16	81.29	18.24	165.8	29.1	9506	0.27	61.4	67.2
BC_17	145.77	30.51	261.0	43.1	10399	1.12	238.3	188.7
BC_18	124.81	29.90	301.1	55.4	10198	0.90	85.5	153.0
BC_19	164.65	40.97	403.7	69.5	13748	1.24	108.2	222.1
BC_20	80.04	16.68	150.2	25.4	9028	0.97	43.0	82.9
BC_21	11.63	2.20	17.2	2.5	11603	0.37	36.3	300.5
BC_22	229.25	51.45	503.0	85.6	13765	2.93	245.1	1553.9
BC_23	54.16	14.03	143.4	26.3	8616	0.33	33.4	139.5
BC_24	105.96	25.48	247.1	41.9	11813	1.35	55.1	466.3
BC_25	257.24	57.43	565.3	91.2	7671	1.00	86.9	96.5
BC_26	30.24	6.58	58.4	9.8	12349	0.52	69.5	87.0
BC_27	30.43	6.12	53.7	9.1	12884	0.49	27.1	473.5
BC_28	24.80	6.26	66.1	13.3	8753	0.33	58.1	103.1
BC_29	107.99	24.83	238.6	39.7	9655	0.50	43.3	75.2
BC_30	79.90	18.19	176.0	31.1	9002	0.76	54.0	98.9
BC_31	143.35	31.28	292.5	50.0	10311	1.34	71.3	270.9
BC_32	46.66	10.78	102.7	18.5	8002	0.09	136.7	1131.8

Data Table 8. Zircon trace element values (ppm) for Top Calico Rock (CR)

*Red text denotes discarded samples

Sample	207/206 Age	Ti49	Y89	Zr91	Nb93	La139	Ce140	Pr141
CR_1	2714.8	9.82	89.5	530167	0.60	0.01	10.43	0.04
CR_2	1167.1	13.72	178.2	512787	1.89	0.01	5.99	0.02
CR_3	1849.4	25.23	107.1	491981	0.30	0.65	3.32	1.64
CR_4	1174.3	14.32	265.1	529584	1.56	0.01	4.49	0.03
CR_5	1044.9	5.56	320.7	526541	4.26	0.01	12.39	0.03
CR_6	2541.3	18.39	97.2	466908	1.21	0.01	15.41	0.08
CR_7	1039.7	5.35	244.5	483870	3.03	0.01	7.39	0.02
CR_8	2704.0	12.91	125.8	460929	0.81	0.01	8.79	0.08
CR_9	1075.5	17.69	130.0	504023	0.77	0.00	4.94	0.05
CR_10	2651.0	4.89	245.9	463189	0.97	0.01	4.46	0.04
CR_11	1080.0	3.15	99.0	433597	1.53	0.01	7.87	0.02
CR_12	2643.8	5.64	190.2	413579	1.45	0.01	5.53	0.03
CR_13	1093.7	5.58	63.7	493116	25.96	0.01	16.98	0.06
CR_14	2619.3	5.64	34.0	514839	0.49	0.01	0.65	0.02
CR_15	2642.9	4.98	566.2	484001	2.86	0.01	14.14	0.03
CR_16	1101.0	7.76	845.4	473579	1.74	0.01	29.02	0.07
CR_17	1013.9	6.86	689.4	464912	0.84	0.01	0.62	0.05
CR_18	1111.8	11.32	770.3	480478	3.60	0.01	20.23	0.05
CR_19	2509.2	16.49	2990.4	455835	20.20	1.00	27.71	5.18
CR_20	2694.9	18.87	277.5	443260	0.74	0.01	19.60	0.06
CR_21	1182.1	7.73	392.4	439554	1.78	0.01	10.99	0.03
CR_22	1104.2	19.05	1158.0	430058	1.12	1.19	43.14	6.20
CR_23	1005.9	4.07	920.3	443038	3.63	0.01	10.66	0.03
CR_24	1083.4	17.74	851.2	476374	2.09	16.43	421.37	27.49
CR_25	1140.7	10.69	1363.5	461996	4.63	0.01	62.27	0.10
CR_26	1131.2	5.30	1263.3	461330	3.50	0.05	11.48	0.42
CR_27	2995.1	177.37	358.7	504051	7.14	3.98	243.59	35.05
CR_28	1047.4	10.46	1623.4	488986	4.73	0.01	50.50	0.11
CR_29	1062.8	8.88	900.8	496699	9.08	0.01	44.13	0.08
CR_30	1076.1	26.69	1827.2	457804	0.69	0.01	15.80	0.30
CR_31	1185.3	9.78	1635.1	468975	1.20	0.01	14.40	0.11
CR_32	2715.4	8.48	1585.6	454863	1.24	0.01	6.52	0.04
CR_33	1947.7	4.19	435.9	508582	4.45	0.01	2.76	0.05
CR_34	1159.3	11.12	1993.5	420204	11.29	0.01	10.75	0.21
CR_35	1172.0	6.28	3182.4	491470	2.35	0.01	11.66	0.24
CR_36	1828.4	10.62	744.0	453669	1.36	0.01	4.04	0.05
CR_37	2116.3	7.62	987.1	460038	2.86	0.01	37.35	0.08
CR_38	1049.3	5.95	1595.7	450917	9.72	0.01	53.55	0.05
CR_39	2661.1	4.80	724.4	434901	2.59	0.01	17.33	0.04
CR_40	2650.9	8.70	430.0	450369	2.01	0.02	13.04	0.05
CR_41	2700.4	13.93	449.1	437988	1.31	0.01	40.93	0.09
CR_42	1023.4	9.89	996.3	449832	4.95	0.01	23.34	0.07

Data Table 8. Zircon trace element values (ppm) for Top Calico Rock (CR) (CONT.)

Sample	Nd146	Sm147	Eu151	Eu153	Gd157	Tb159	Dy163	Ho165
CR_1	0.44	0.74	0.42	0.41	2.53	0.80	9.21	3.23
CR_2	0.21	0.39	0.13	0.13	2.00	0.92	13.90	6.20
CR_3	8.09	5.46	1.37	1.59	7.4	2.0	18.00	4.53
CR_4	0.28	0.52	0.09	0.09	2.70	1.30	20.17	8.91
CR_5	0.32	0.64	0.17	0.18	3.25	1.48	23.13	10.43
CR_6	0.65	0.78	0.42	0.46	2.38	0.81	9.62	3.42
CR_7	0.21	0.49	0.14	0.14	2.50	1.14	18.30	8.39
CR_8	0.68	0.80	0.32	0.33	2.86	0.92	11.80	4.55
CR_9	0.39	0.62	0.21	0.22	2.57	1.00	12.87	4.98
CR_10	0.40	0.90	0.38	0.39	3.93	1.53	21.05	8.20
CR_11	0.18	0.18	0.12	0.12	0.87	0.39	7.19	3.60
CR_12	0.29	0.54	0.19	0.21	2.46	0.98	14.07	5.97
CR_13	0.48	1.16	0.29	0.33	7.41	4.56	87.29	43.97
CR_14	0.11	0.17	0.14	0.17	0.78	0.31	3.90	1.34
CR_15	0.31	0.94	0.32	0.36	5.88	2.74	39.45	15.86
CR_16	1.17	3.10	0.67	0.78	16.23	6.16	75.88	25.23
CR_17	0.85	3.76	0.28	0.29	27.47	10.70	97.77	19.29
CR_18	0.64	2.00	0.31	0.30	9.77	4.28	60.32	22.47
CR_19	36.55	34.07	5.31	6.17	53.66	18.54	218.50	72.04
CR_20	0.99	2.26	0.67	0.76	8.77	2.74	27.88	8.60
CR_21	0.37	0.96	0.30	0.28	4.51	1.87	26.60	10.75
CR_22	46.15	37.04	6.97	7.83	53.04	14.77	135.99	33.28
CR_23	0.35	1.24	0.42	0.47	10.13	4.57	65.67	26.32
CR_24	121.93	28.82	2.94	3.16	35.87	8.44	84.33	25.30
CR_25	1.60	3.67	0.83	0.93	21.20	8.20	107.74	36.46
CR_26	3.59	5.20	0.56	0.67	20.83	8.08	103.74	36.03
CR_27	306.17	264.20	39.83	45.00	387.24	107.31	962.91	218.48
CR_28	2.24	4.81	0.73	0.79	24.31	9.32	124.02	43.70
CR_29	1.12	2.67	0.30	0.31	13.32	5.67	75.06	26.76
CR_30	4.52	6.57	1.87	2.05	26.95	10.74	143.60	50.84
CR_31	1.92	3.67	1.30	1.34	17.93	7.32	106.41	42.19
CR_32	0.82	2.39	0.54	0.56	15.88	7.16	107.53	42.67
CR_33	0.37	0.64	0.17	0.15	3.56	1.89	31.29	12.74
CR_34	3.08	6.37	0.61	0.69	29.08	11.92	161.80	55.49
CR_35	4.14	8.03	0.47	0.58	39.31	15.96	213.47	77.47
CR_36	0.79	3.59	0.44	0.45	19.19	7.39	79.91	21.94
CR_37	0.72	1.75	0.52	0.47	10.80	4.84	70.05	26.54
CR_38	0.86	2.49	0.41	0.39	16.30	7.51	111.40	43.19
CR_39	0.55	2.18	0.31	0.35	12.16	4.92	64.26	22.70
CR_40	0.49	1.23	0.17	0.17	6.37	2.59	36.99	14.09
CR_41	1.33	3.25	0.80	0.87	13.52	4.03	45.00	14.08
CR_42	1.21	3.84	0.95	1.02	17.72	7.12	90.51	30.81

Data Table 8. Zircon trace element values (ppm) for Top Calico Rock (CR) (CONT.)

Sample	Er166	Tm169	Yb172	Lu175	Hf179	Ta181	Th232	U238
CR_1	15.29	3.98	38.7	7.1	6504	0.22	15.3	25.7
CR_2	35.45	10.09	110.4	20.9	8465	1.17	22.8	133.2
CR_3	16.48	3.53	29.6	4.1	8370	0.08	42	183.7
CR_4	48.93	13.27	135.3	24.6	8895	0.79	14.7	75.5
CR_5	56.57	15.59	165.3	30.7	8671	1.46	21.3	90.1
CR_6	16.39	4.36	45.8	7.5	5271	0.62	45.0	104.9
CR_7	46.92	13.58	152.0	27.6	6969	1.20	17.1	71.0
CR_8	23.10	5.94	60.6	10.8	6502	0.42	42.5	108.4
CR_9	24.97	6.35	63.8	11.5	5933	0.36	9.2	38.6
CR_10	41.35	11.12	117.4	20.2	7402	0.60	54.5	122.2
CR_11	24.80	8.39	108.7	19.3	4979	0.35	15.4	166.8
CR_12	34.00	10.16	119.8	21.1	7597	1.70	29.9	122.7
CR_13	269.43	73.62	849.8	139.3	8731	6.37	50.5	299.3
CR_14	5.61	1.18	9.6	1.5	6668	0.42	4.9	126.5
CR_15	82.14	21.68	237.5	47.0	11788	1.96	251.2	281.0
CR_16	108.26	24.49	240.5	40.0	10070	0.67	135.4	170.9
CR_17	49.55	7.45	49.2	6.0	11369	0.73	21.1	470.2
CR_18	110.88	26.73	280.8	48.0	10746	1.88	96.3	217.7
CR_19	338.24	79.54	797.7	131.4	11372	9.34	214.5	767.9
CR_20	35.35	7.59	75.0	12.1	8086	0.33	99.8	95.1
CR_21	56.17	14.93	168.9	29.7	6709	0.71	137.2	218.5
CR_22	128.29	27.31	269.2	41.9	8170	0.28	334.8	941.0
CR_23	130.43	32.49	356.8	61.2	9844	2.22	72.7	304.5
CR_24	108.75	25.05	254.8	42.4	9829	1.17	96.4	170.4
CR_25	167.92	38.36	390.9	62.3	9756	2.08	163.3	242.6
CR_26	158.96	35.01	336.4	56.2	8347	1.57	177.3	312.6
CR_27	756.25	136.84	1127.5	173.1	12508	4.45	659.3	1432.3
CR_28	206.40	45.61	454.3	79.2	10020	1.49	164.3	130.8
CR_29	120.10	28.54	282.6	51.6	11612	3.84	64.8	138.5
CR_30	218.22	46.62	449.7	73.4	7872	0.42	193.6	152.9
CR_31	222.47	58.78	687.8	129.6	10987	0.86	452.2	448.1
CR_32	210.78	51.09	524.5	93.6	9337	0.58	38.0	65.5
CR_33	67.35	16.60	165.6	31.8	15324	2.80	31.2	465.6
CR_34	237.85	53.84	526.6	73.6	6540	2.99	135.1	310.4
CR_35	339.79	74.48	674.4	108.3	11348	1.35	243.4	481.9
CR_36	81.56	16.47	142.0	21.5	11518	0.72	82.9	548.1
CR_37	130.02	33.36	341.6	59.8	9623	1.39	203.7	429.8
CR_38	213.53	52.02	553.1	91.9	10392	3.82	215.9	375.6
CR_39	95.61	21.30	208.0	32.0	10735	1.51	143.7	220.7
CR_40	66.16	16.19	165.1	27.6	10379	1.12	91.7	250.7
CR_41	57.93	13.33	129.6	20.4	8268	0.61	144.3	119.9
CR_42	132.78	31.11	314.3	48.1	9074	2.65	61.7	104.1